Developing an AVHRR-based CDR of TOA radiative fluxes within the CMSAF Project: SW fluxes

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34th CERES Science Team Meeting

Virtual meeting, September 15-18, 2020

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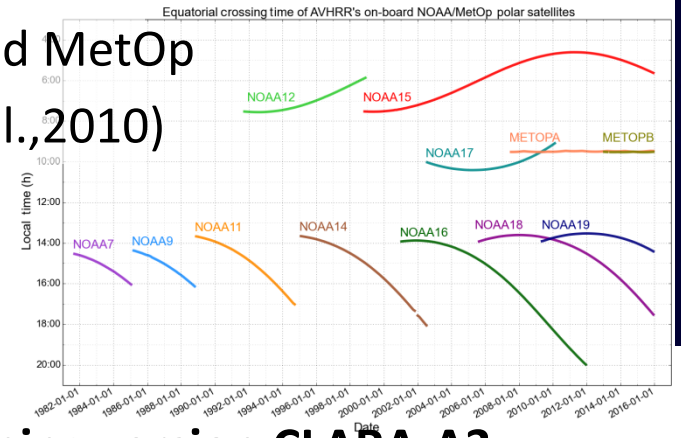
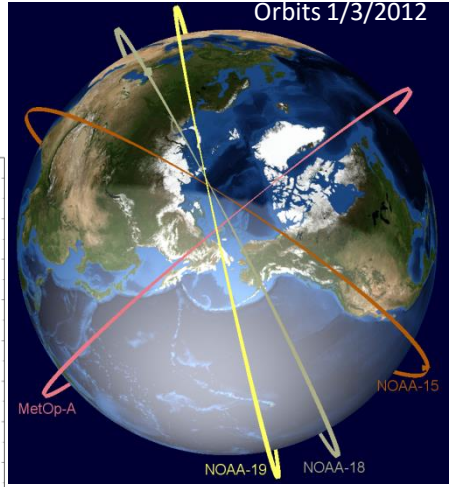
1. Introduction

What is CLARA? "CM SAF cLoud, Albedo and RAdiation dataset from AVHRR data" (=*Similar to Patmos-X)*

- Polar orbiting satellites NOAA and MetOp
- FCDR from NOAA (Heidinger et al.,2010)
- Currently released versions:
  - CLARA-A1 (1982-2009)
  - CLARA-A2 (1982-2015)





Some of the modifications in upcoming version CLARA-A3:

- Inclusion of AVHRR-1 sensor (TIROS-N, NOAA-6, -8, -10): extension of time range to 1978-2019 i.e. 42yr
- Updated FCDR: new calibration for visible channels (latest PATMOS-x coefficients)
- Updated cloud treatment algorithms (NWCSAF/PPS v.2018; Karlsson et al.) SMHI
- Addition of new product "TOA radiative fluxes" -> this presentation

1. Introduction

Level-2 processing: instantaneous observations

Part1 / Part2

Outgoing Longwave Radiation (OLR)

AVHRR ch4: 11µ | AVHRR ch5: 12µ → FREQUENCY (Hz)

"all-in-one" conversion from narrowband directional brightness temp. to broadband hemispherical flux, based on database with coangular AVHRR-CERES obs.

OLR *[W/m²]* → FREQUENCY (Hz)

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped OLR (0.25°)

Reflected Solar Flux (RSF)

AVHRR ch1: 0.6µ | AVHRR ch2: 0.9µ → FREQUENCY (Hz)

NB-to-BB regressions based on database with co-angular AVHRR-CERES obs.

Broadband reflectance → FREQUENCY (Hz)

ADM's from CERES Ed2B: TRMM, +TERRA for snow/ice

Albedo *[%]* *(hemispherical)* → FREQUENCY (Hz)

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped Albedo (0.25°)

Level-3 processing: daily mean

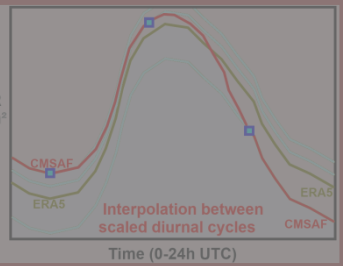
Part3

OLR

ERA5 diurnal cycle OLR

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate :

Daily mean

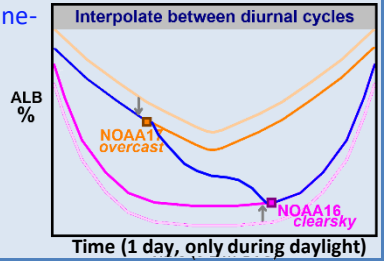


RSF

Method: Young et al. ('98): match scene-dependent average diurnal cycle to observations, then interpolate

Convert albedo to flux

Daily mean RSF [W/m²]



Level-3b processing

P4

OLR

Monthly mean

RSF

Monthly mean RSF

1. Introduction

remote sensing

MDPI

Article

Narrowband-to-Broadband Conversions for Top-of-Atmosphere Reflectance from the Advanced Very High Resolution Radiometer (AVHRR)

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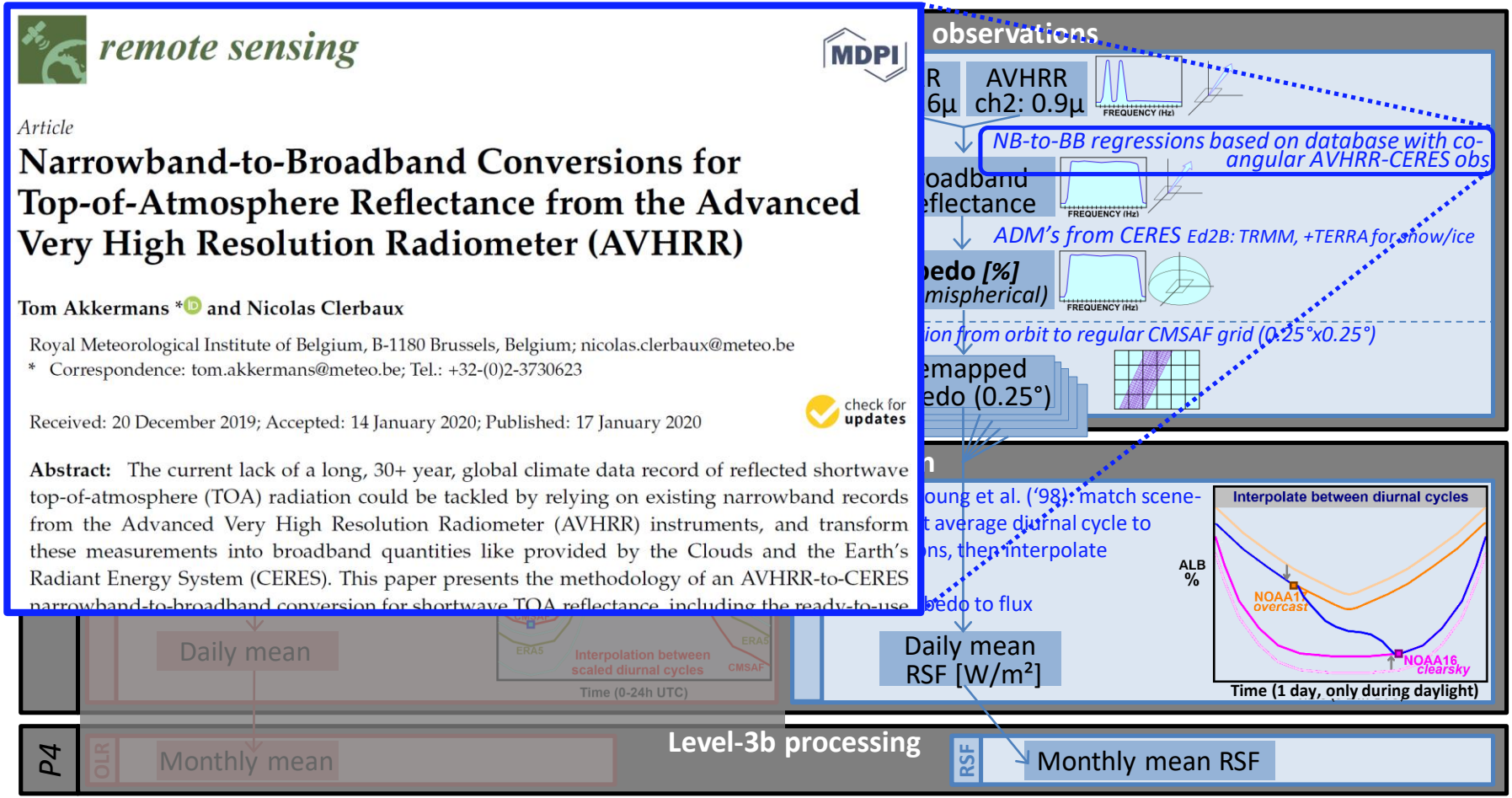
Received: 20 December 2019; Accepted: 14 January 2020; Published: 17 January 2020

check for updates

Abstract: The current lack of a long, 30+ year, global climate data record of reflected shortwave top-of-atmosphere (TOA) radiation could be tackled by relying on existing narrowband records from the Advanced Very High Resolution Radiometer (AVHRR) instruments, and transform these measurements into broadband quantities like provided by the Clouds and the Earth's Radiant Energy System (CERES). This paper presents the methodology of an AVHRR-to-CERES narrowband-to-broadband conversion for shortwave TOA reflectance, including the ready-to-use



1. Introduction

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Outoing Longwave Radiation (OLR)

AVHRR ch4: 11µ | AVHRR ch5: 12µ

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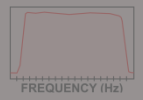
OLR *[W/m²]*



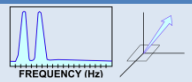
Part2

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped OLR (0.25°)

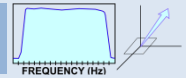
Reflected Solar Flux (RSF)

AVHRR ch1: 0.6µ | AVHRR ch2: 0.9µ



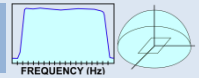
NB-to-BB regressions based on database with co-angular AVHRR-CERES obs.

Broadband reflectance



ADM's from CERES Ed2B: TRMM, +TERRA for snow/ice

Albedo *[%]* *(hemispherical)*



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Level-3 processing: daily mean

Part3

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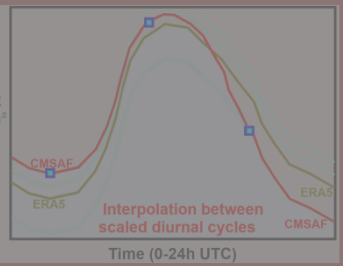

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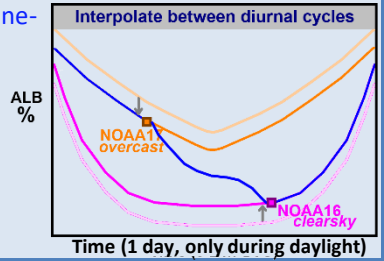
Convert albedo to flux



Daily mean RSF [W/m²]

Level-3b processing

P4

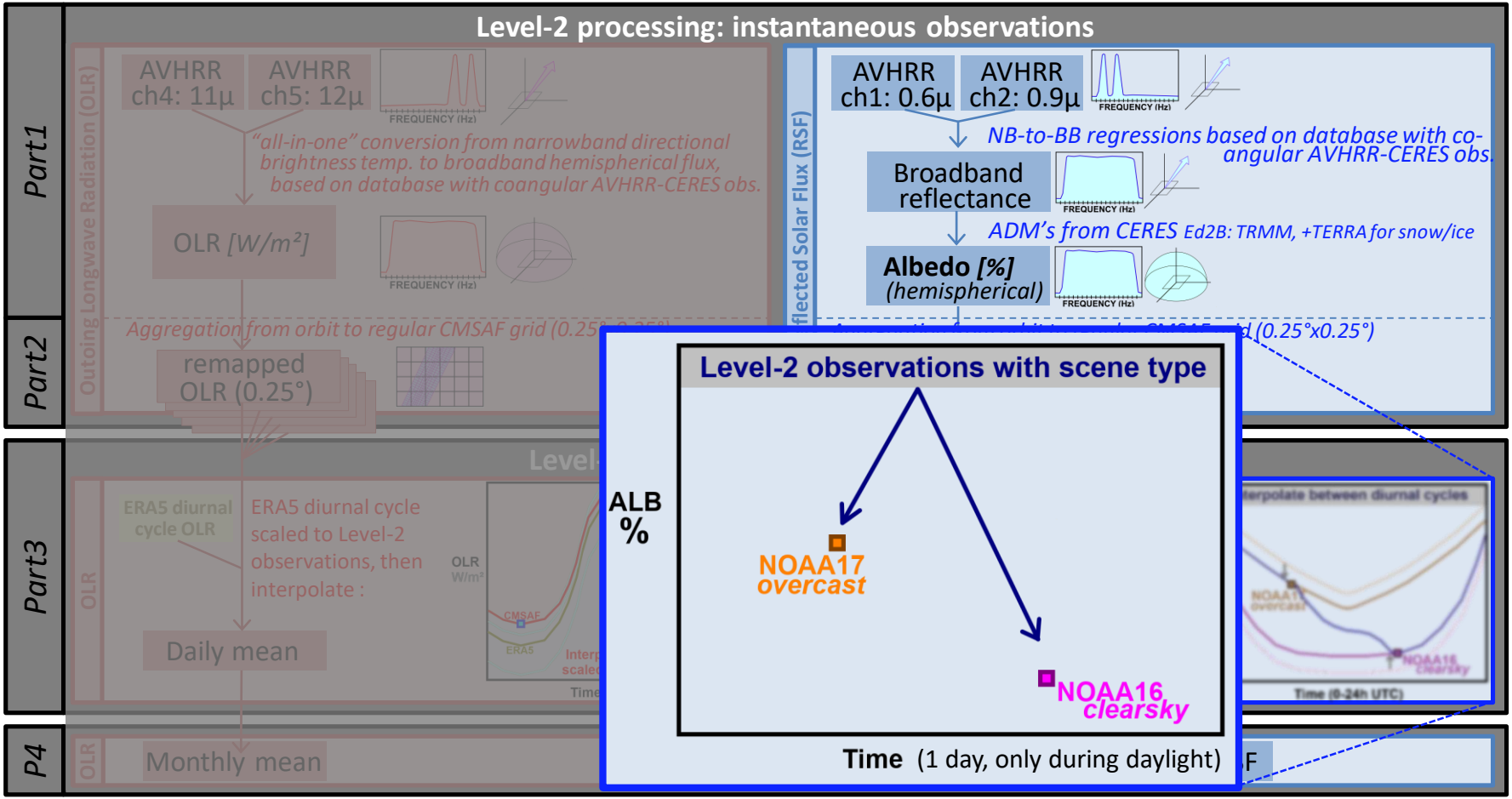
OLR

Monthly mean

RSF

Monthly mean RSF

1. Introduction



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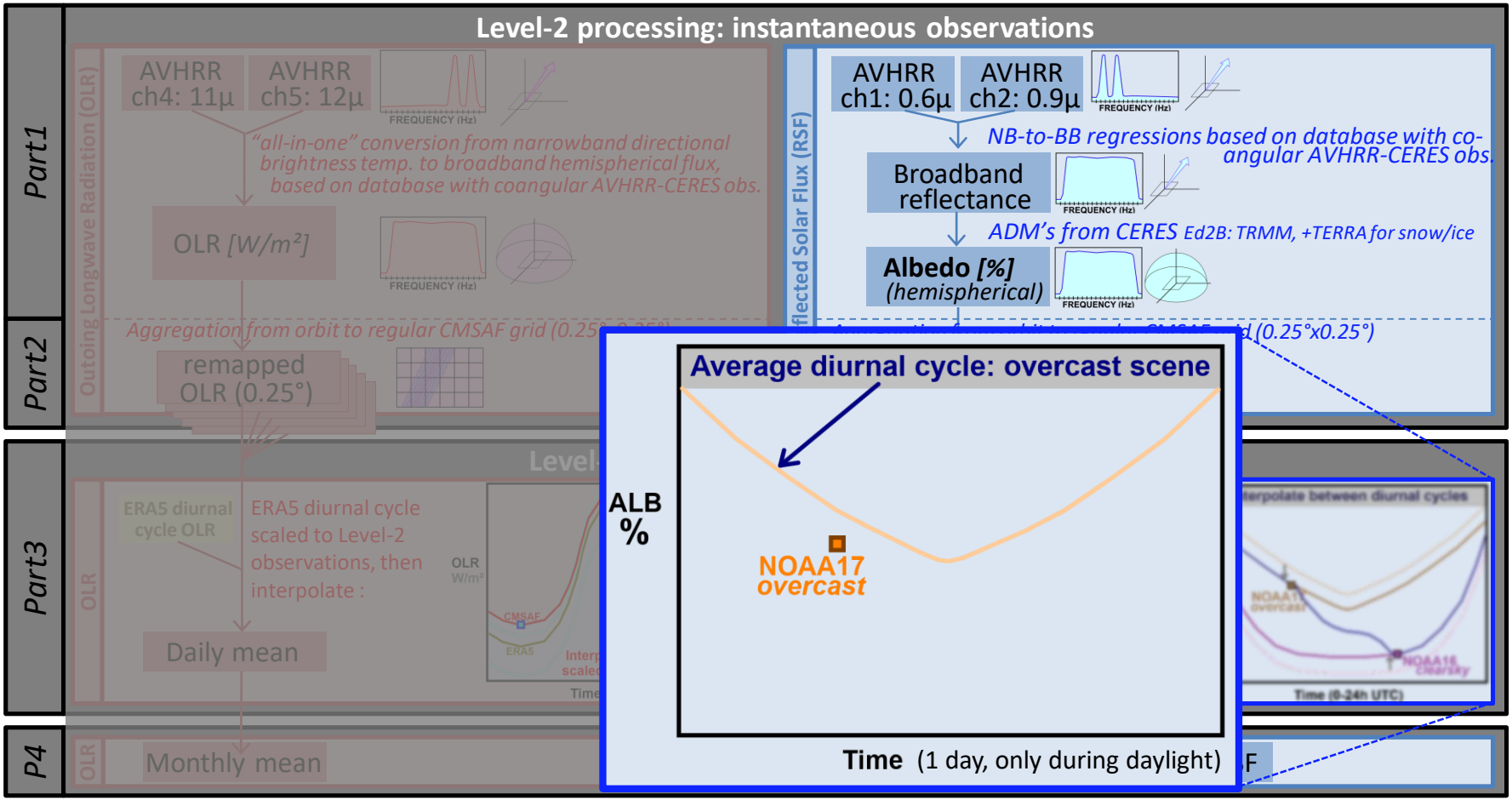

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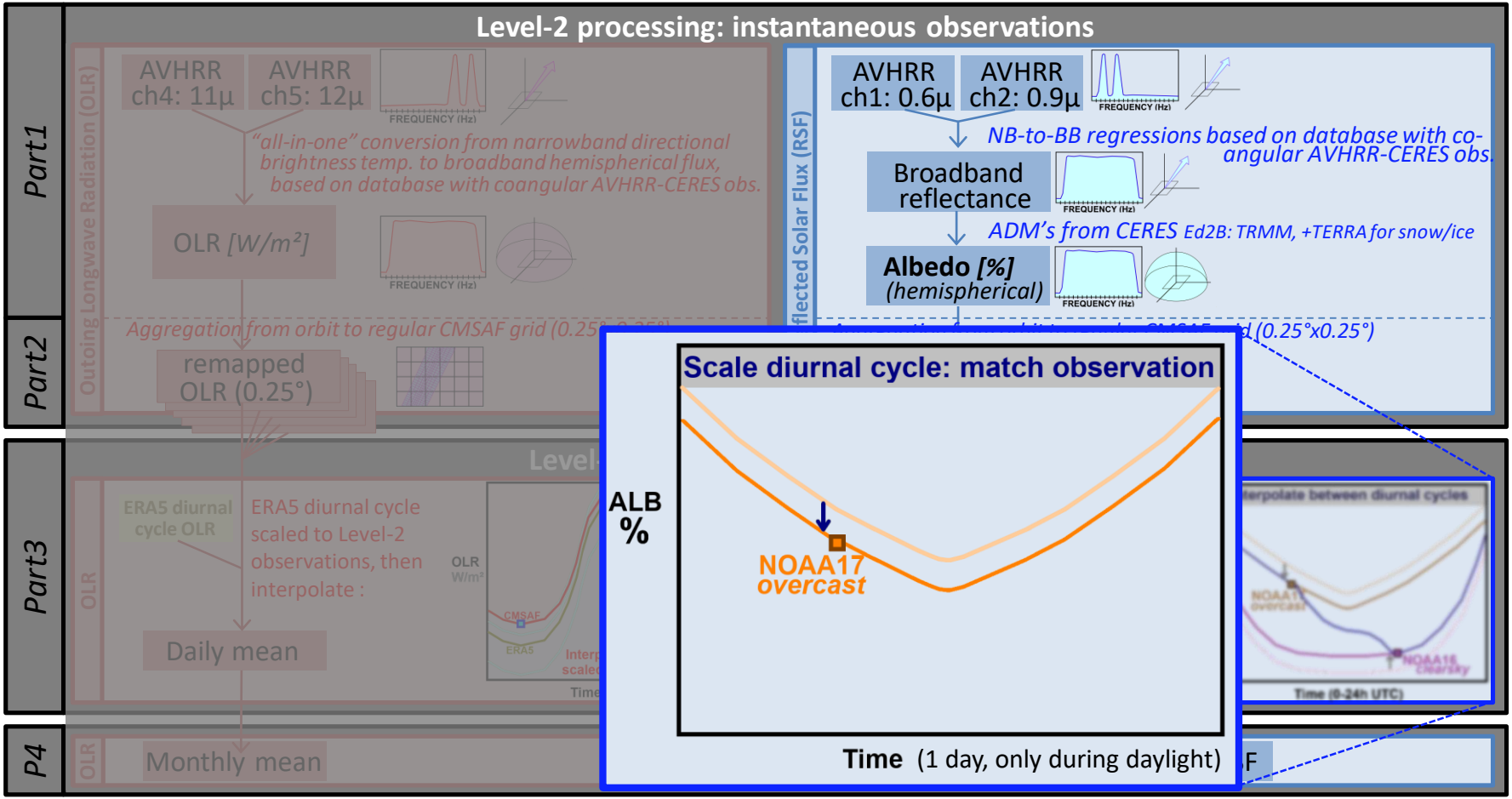

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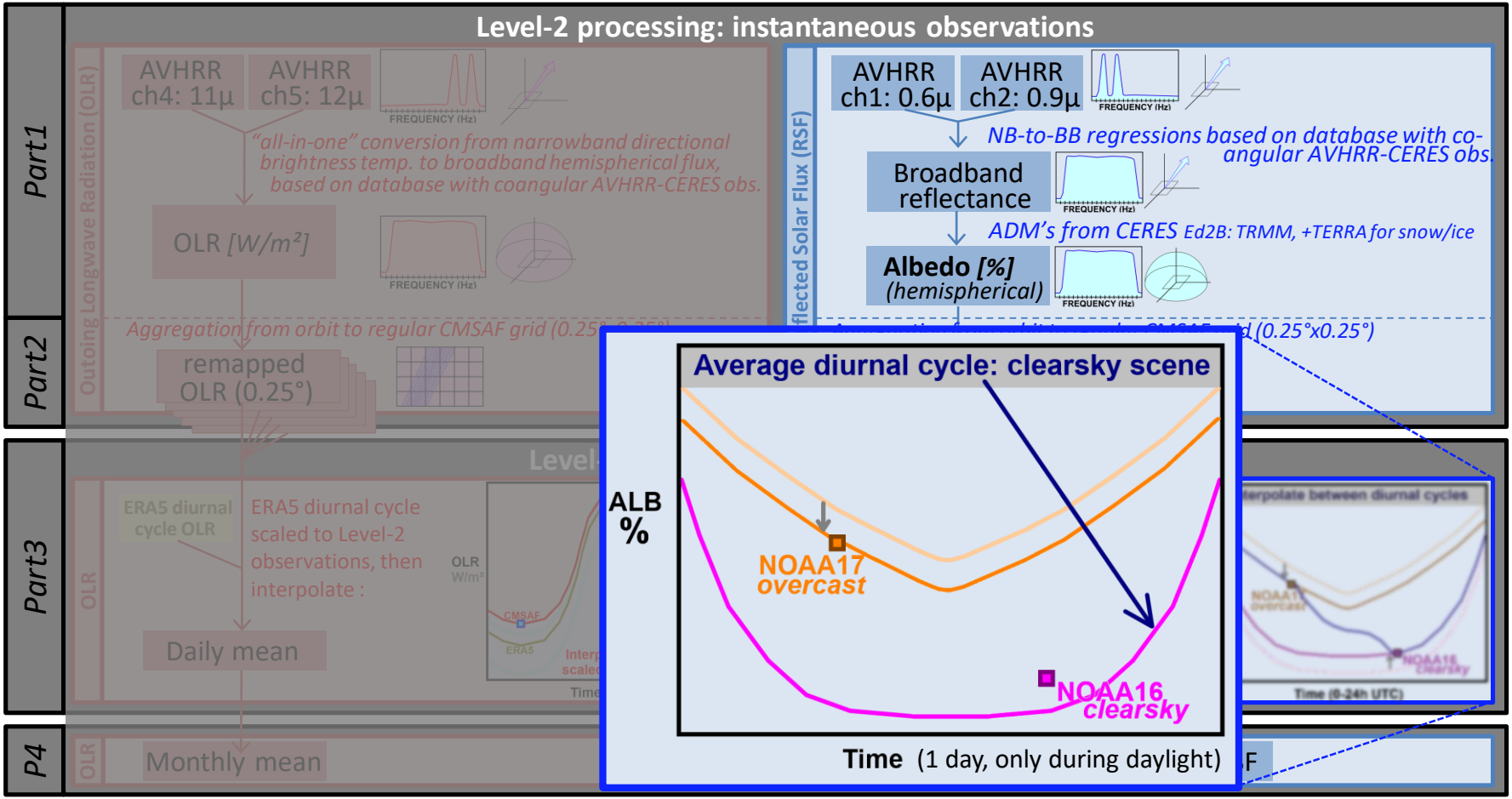

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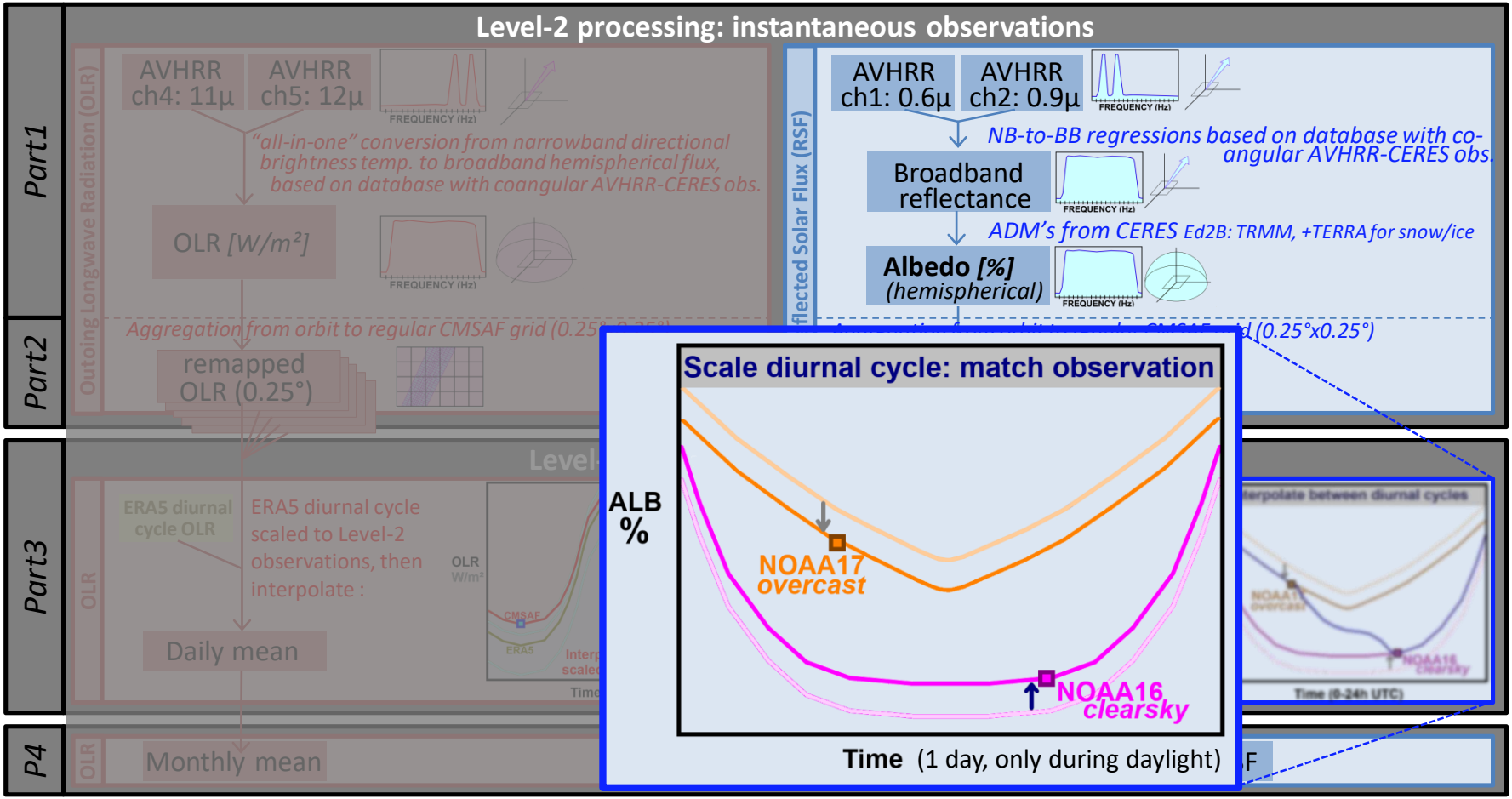

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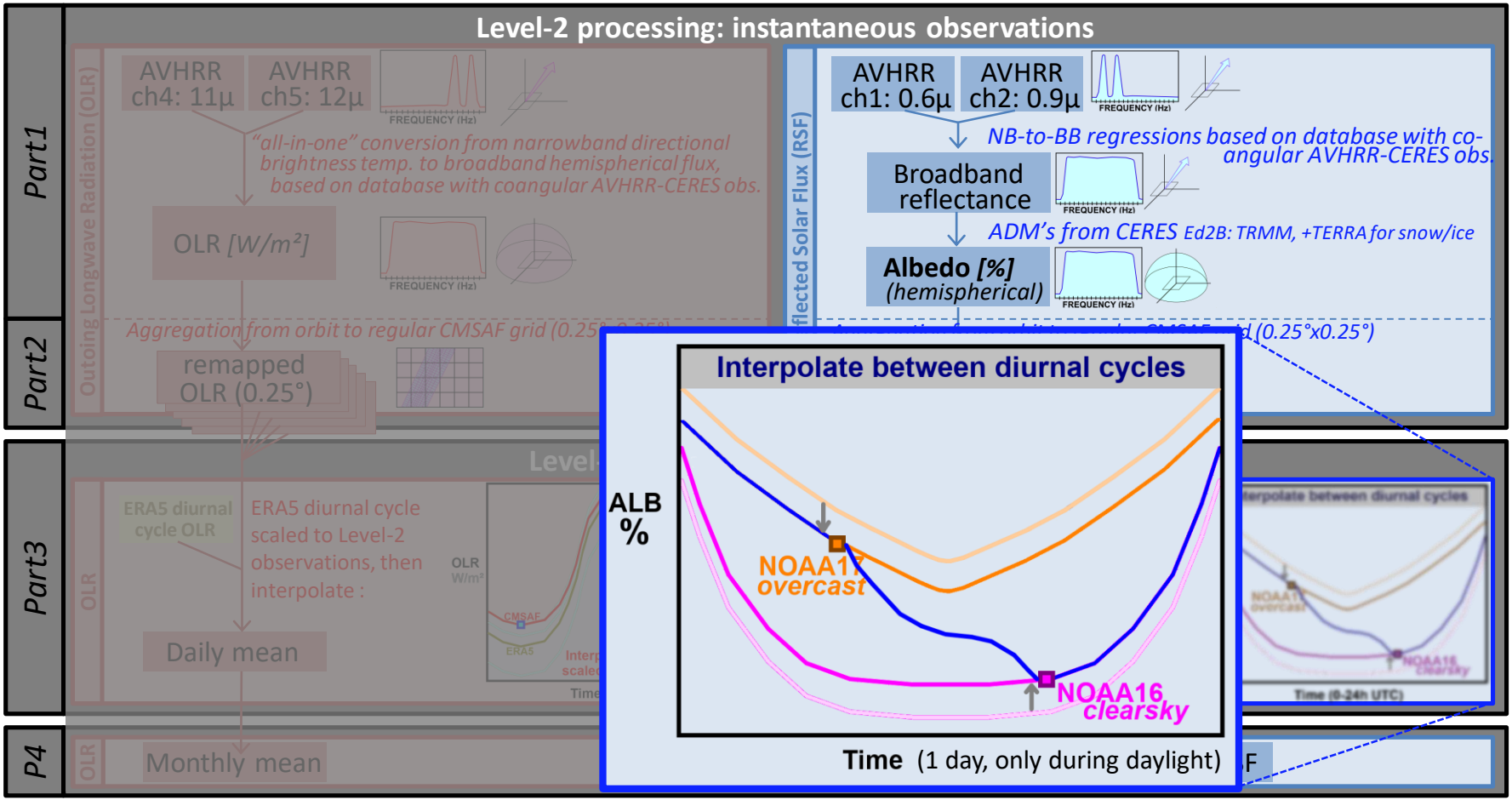

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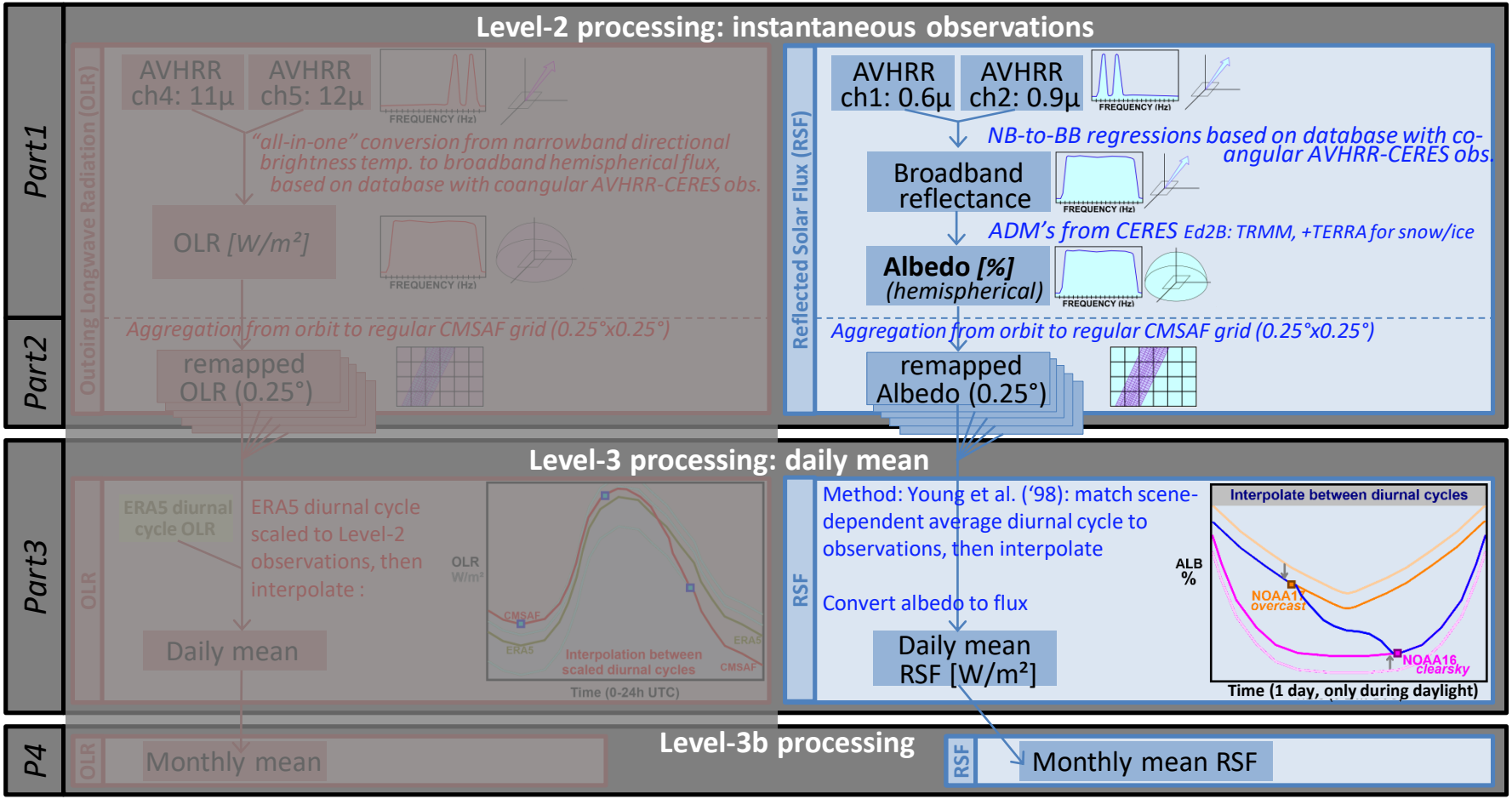
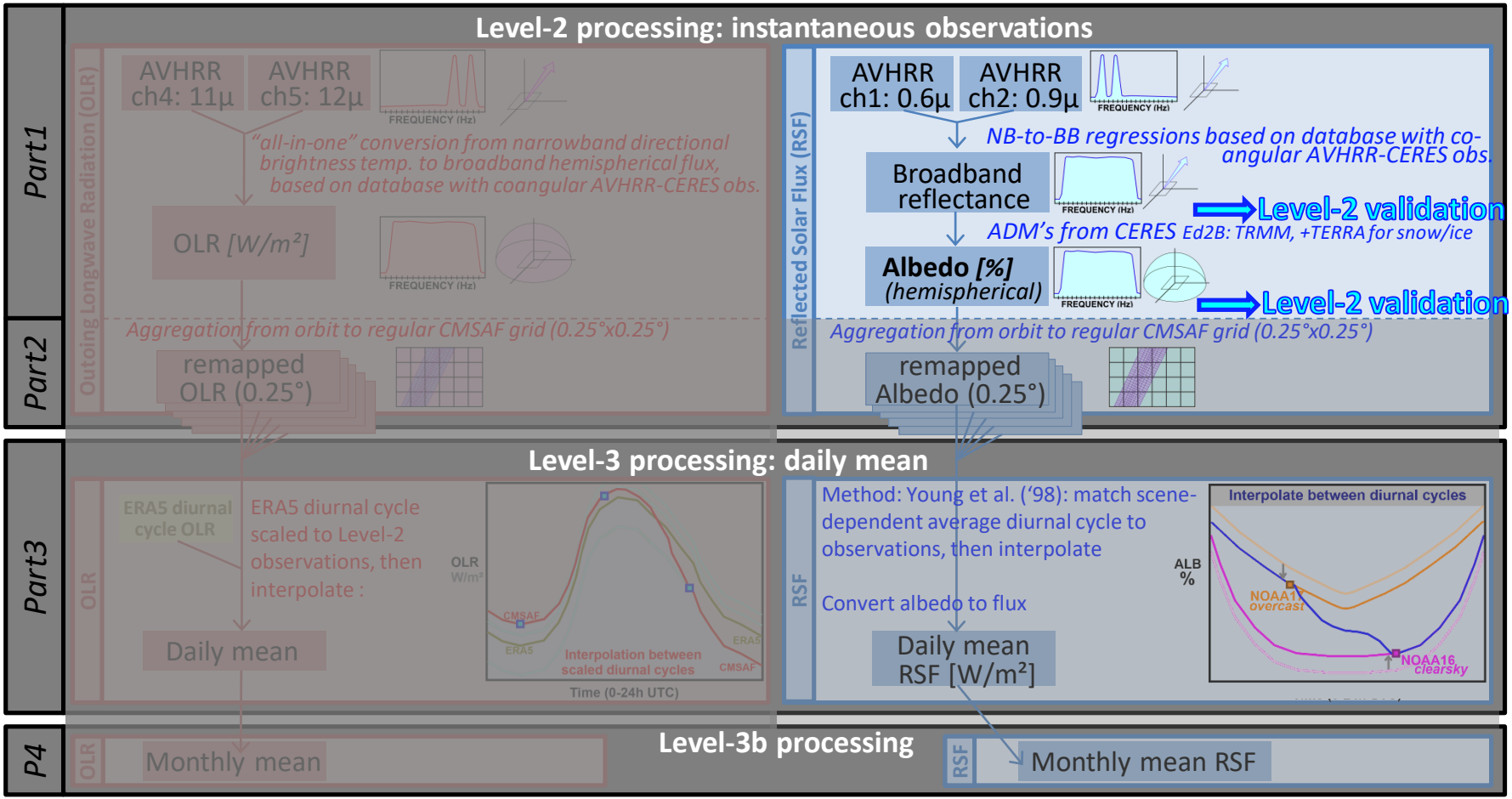


2.1. Validation instantaneous L2

1. Introduction
2. **Validation results:**
   - **2.1. Instantaneous RSF (level-2)**
   - 2.2. Daily and monthly mean RSF (level-3) +Monthly mean diurnal cycle
   - 2.3. Long term time series, stability

2.1. Validation instantaneous L2



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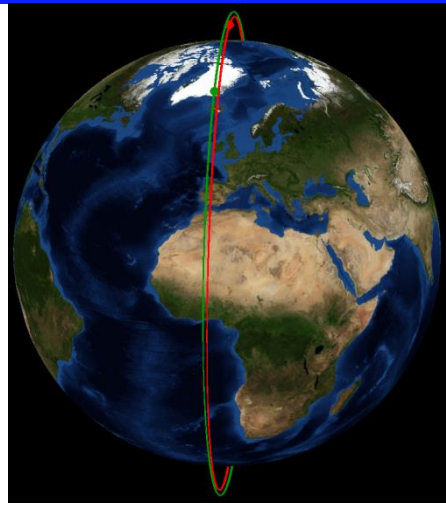
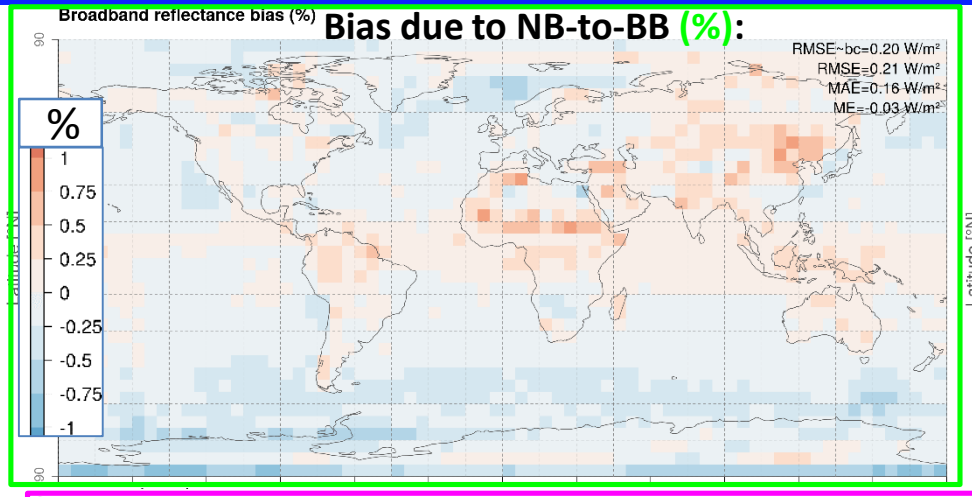
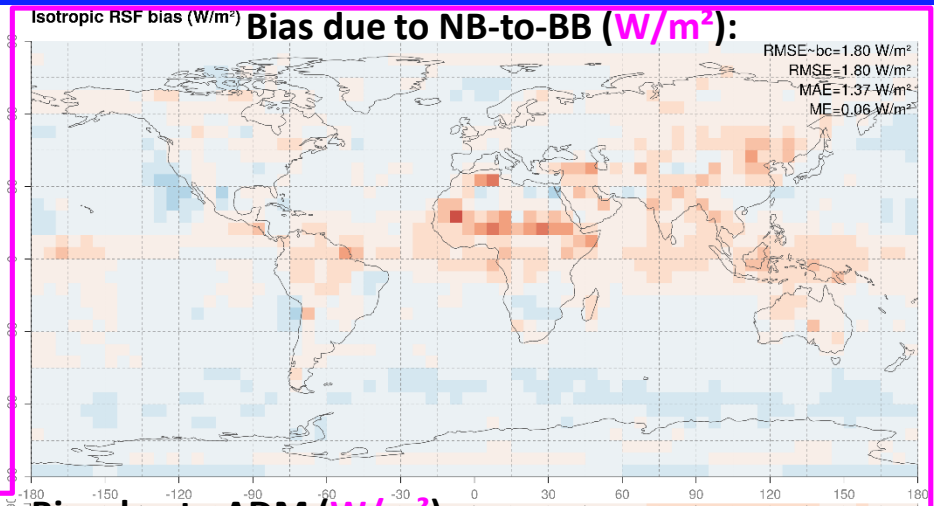
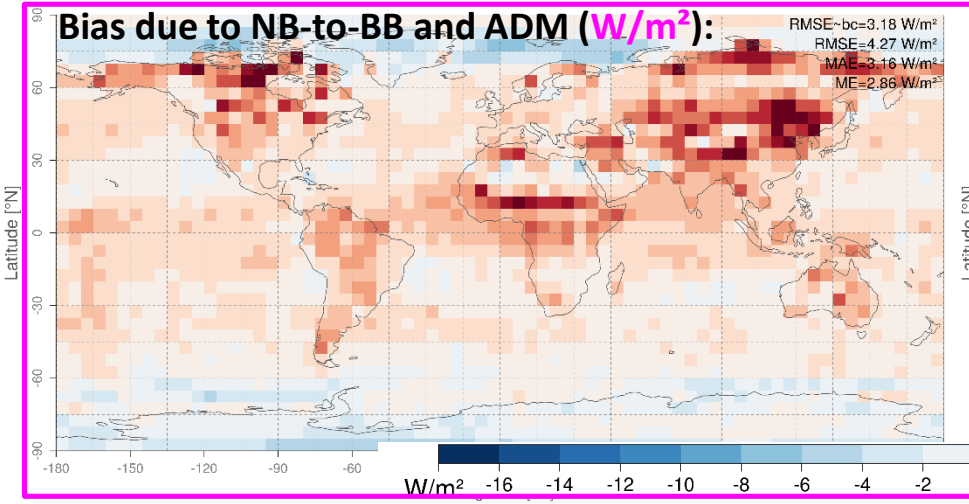


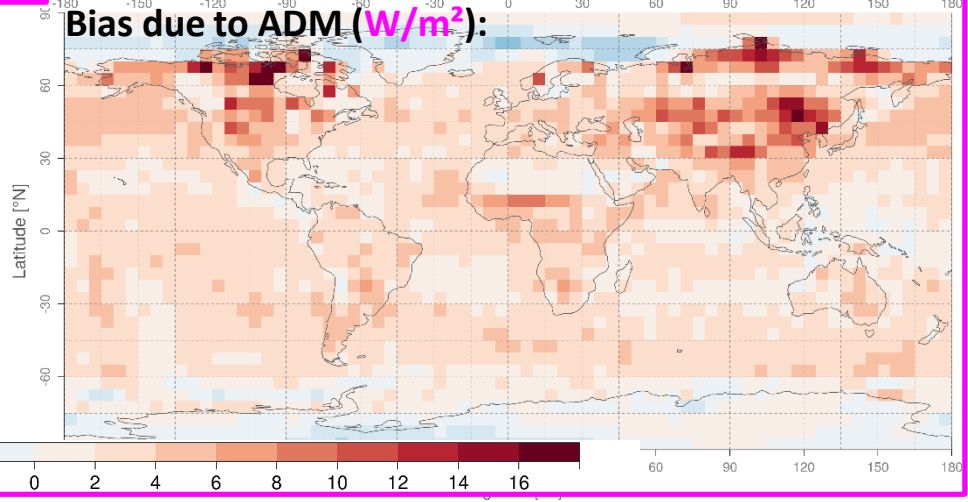
- Validation is done on AVHRR-CERES "**matched observations**", i.e. that are collocated, coangular, and simultaneous. Those conditions are met when orbital planes from Terra/Aqua and NOAA-17/18/19 coïncide (2004, 2005, 2007, 2008, 2011, 2012).
- Method: TOA albedo+RSF is calculated for each AVHRR pixel. Subsequently, for each **CERES-SSF footprint** the matching AVHRR pixel values are averaged and the bias is calculated.
- Number of matched observations: about 66 million
- Biases are gridded in 5°x5° lat-lon boxes. Spatial spread of bias is quantified by bias-corrected RMSE.

2.1. Validation instantaneous L2









2.2. Validation daily/monthly L3

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   - 2.1. Instantaneous RSF (level-2)
   - **2.2. Daily and monthly mean RSF (level-3) +Monthly mean diurnal cycle**
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2.2. Validation daily/monthly L3

Level-2 processing: instantaneous observations

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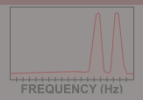

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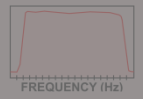
OLR *[W/m²]*



Part2

Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

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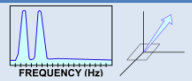

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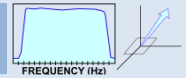
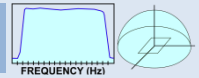
Broadband reflectance



ADM's from CERES Ed2B: TRMM, +TERRA for snow/ice

Albedo *[%]* *(hemispherical)*



Aggregation from orbit to regular CMSAF grid (0.25°x0.25°)

remapped Albedo (0.25°)

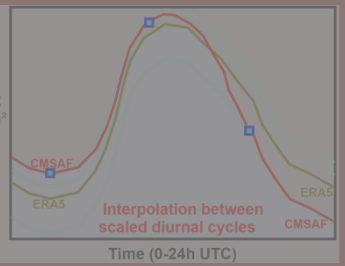
Level-3 processing: daily mean

Part3

OLR

ERA5 diurnal cycle OLR

ERA5 diurnal cycle scaled to Level-2 observations, then interpolate :



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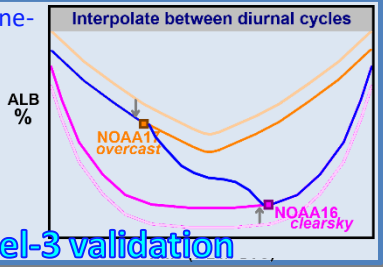


Daily mean RSF [W/m²]

Level-3 validation

Level-3b processing

P4

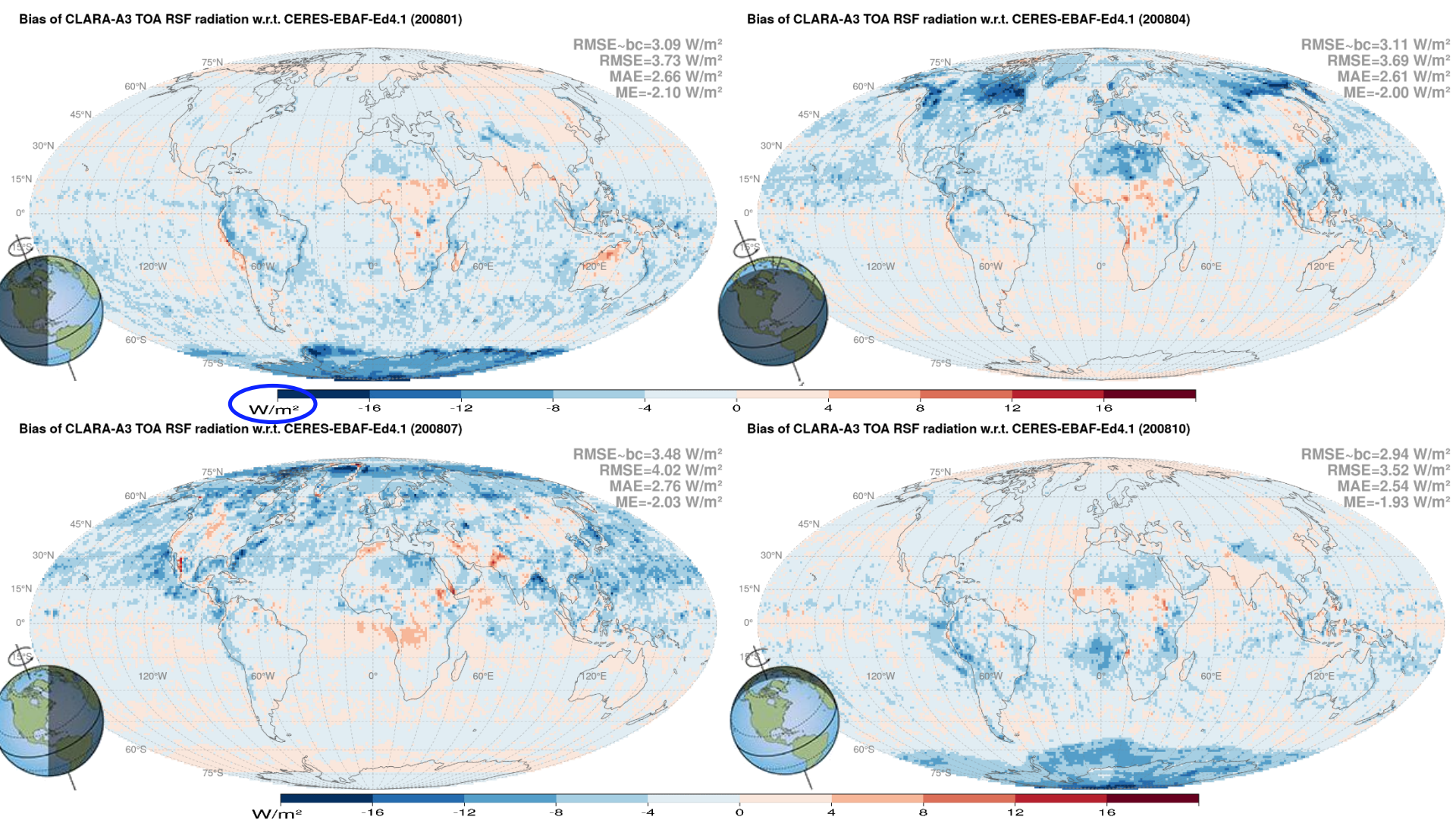
OLR

Monthly mean

RSF

Monthly mean RSF

Level-3 validation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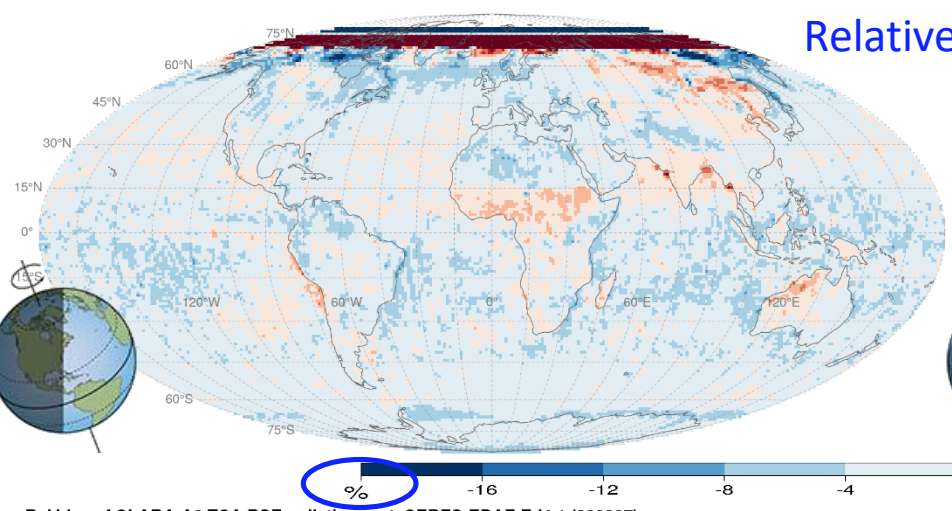
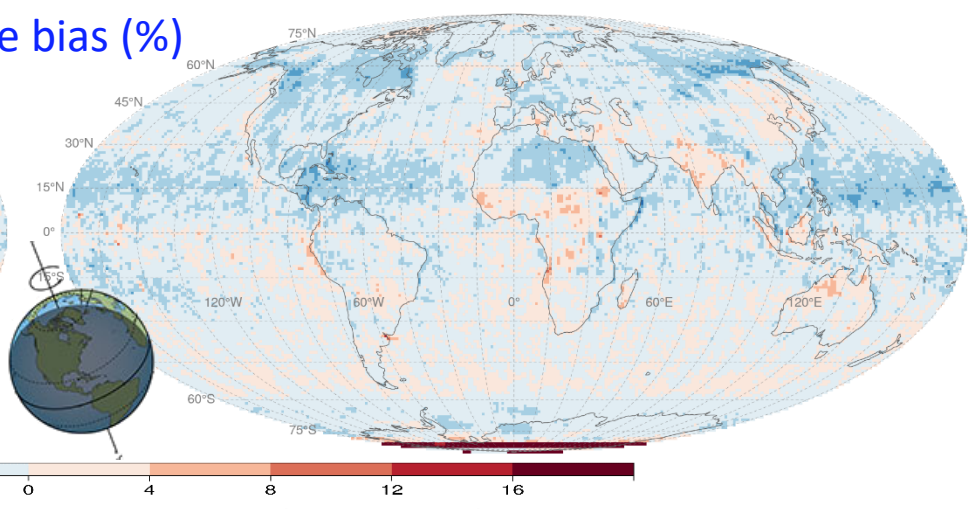
RMSE~bc=3.09 W/m²
RMSE=3.73 W/m²
MAE=2.66 W/m²
ME=-2.10 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (200804)
RMSE~bc=3.11 W/m²
RMSE=3.69 W/m²
MAE=2.61 W/m²
ME=-2.00 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (200807)
RMSE~bc=3.48 W/m²
RMSE=4.02 W/m²
MAE=2.76 W/m²
ME=-2.03 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (200810)
RMSE~bc=2.94 W/m²
RMSE=3.52 W/m²
MAE=2.54 W/m²
ME=-1.93 W/m²
75°N
60°N
45°N
30°N
15°N
0°
15°S
60°S
75°S
120°W
60°W
0°
60°E
120°E
W/m²
-16
-12
-8
-4
0
4
8
12
16

Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (200801)

Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (200804)

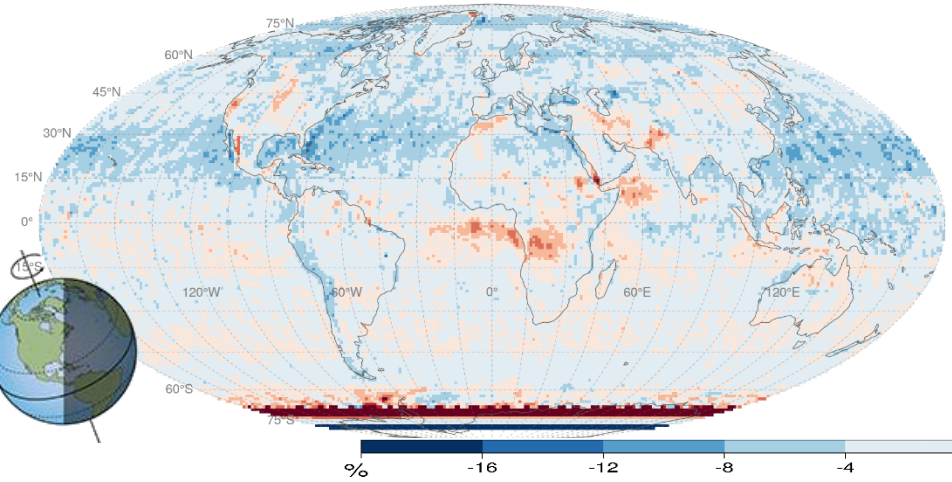
Relative bias (%)

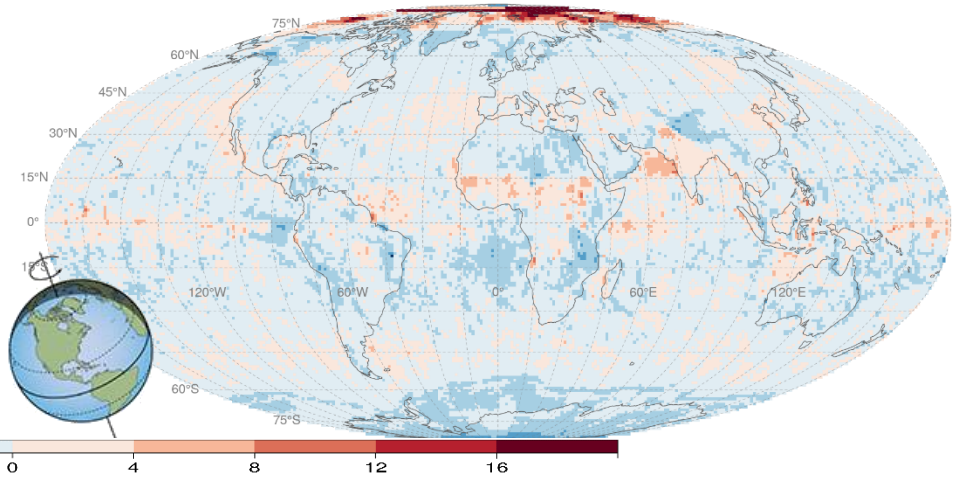


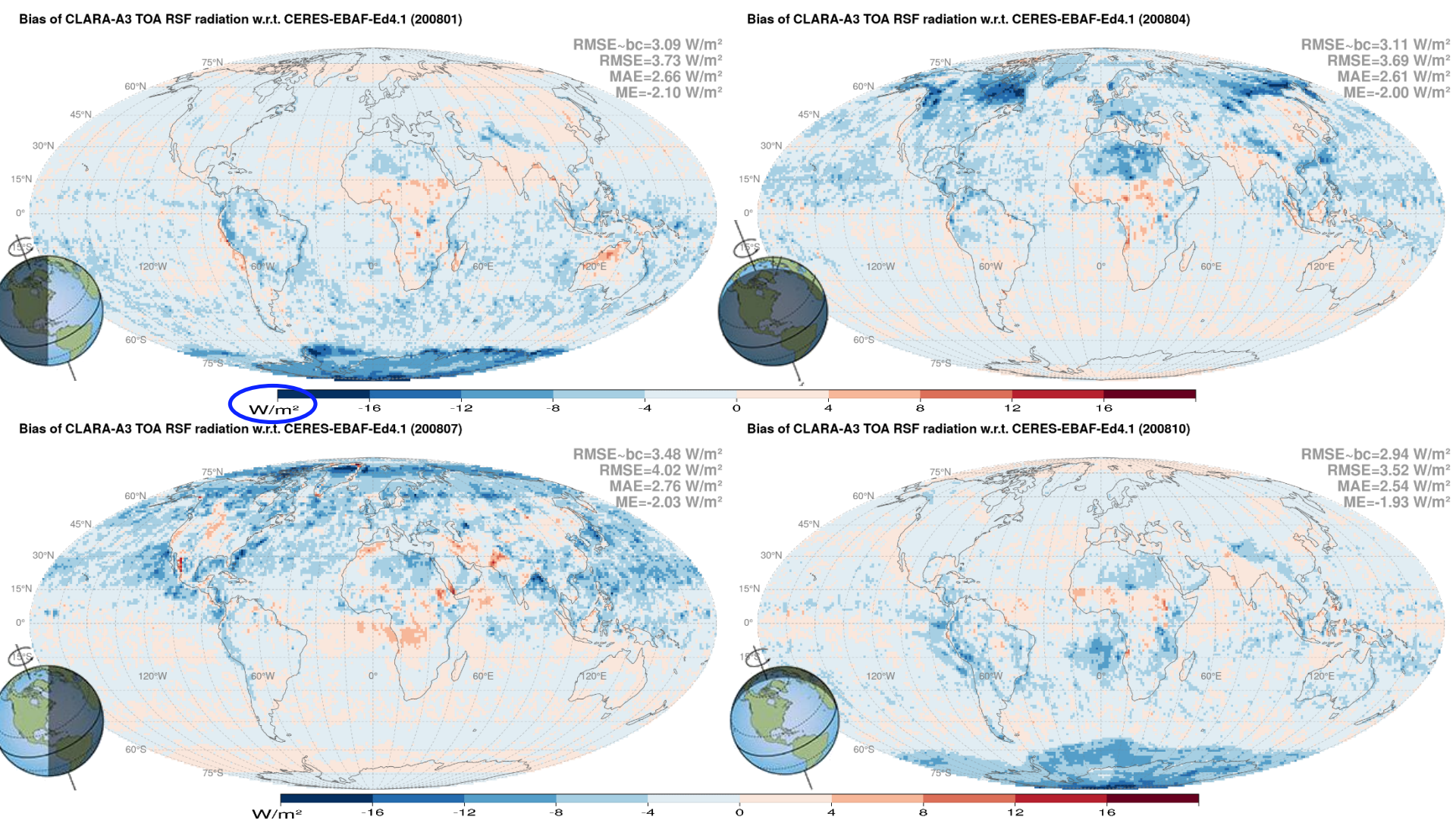


Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (200807)

Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (200810)



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ME=-1.93 W/m²
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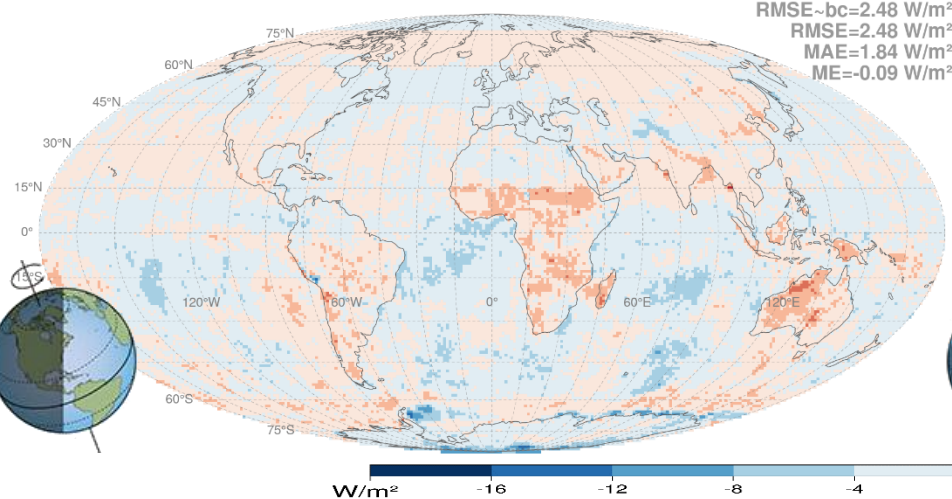
60°N
45°N
30°N
15°N
0°
15°S
60°S
75°S
120°W
60°W
0°
60°E
120°E
W/m²
-16
-12
-8
-4
0
4
8
12
16

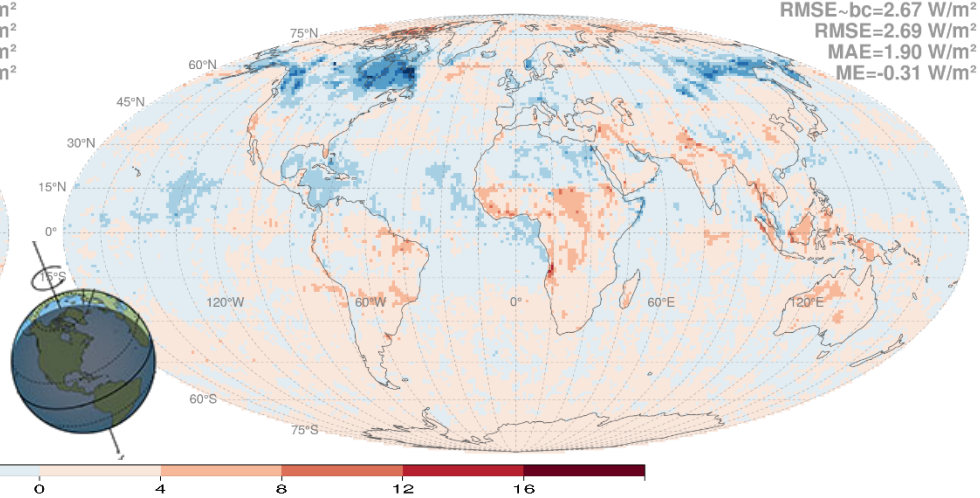
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)

RMSE~bc=2.48 W/m²
RMSE=2.48 W/m²
MAE=1.84 W/m²
ME=-0.09 W/m²



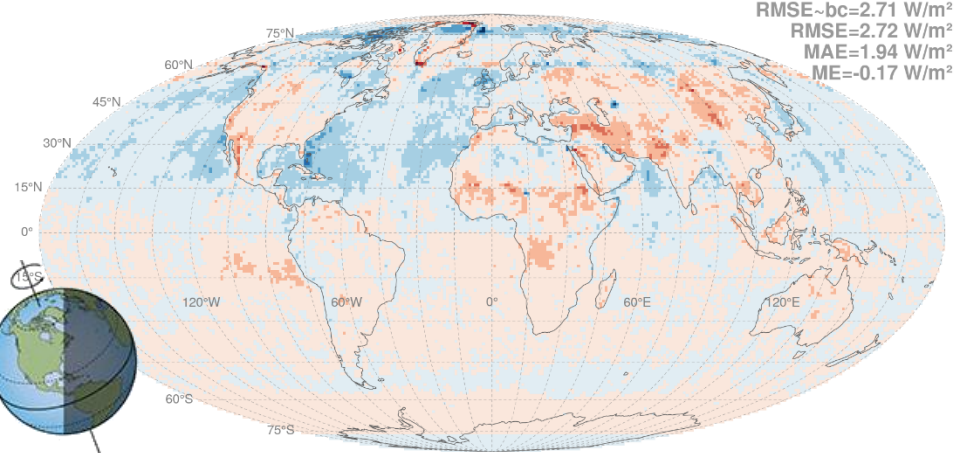
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804)

RMSE~bc=2.67 W/m²
RMSE=2.69 W/m²
MAE=1.90 W/m²
ME=-0.31 W/m²



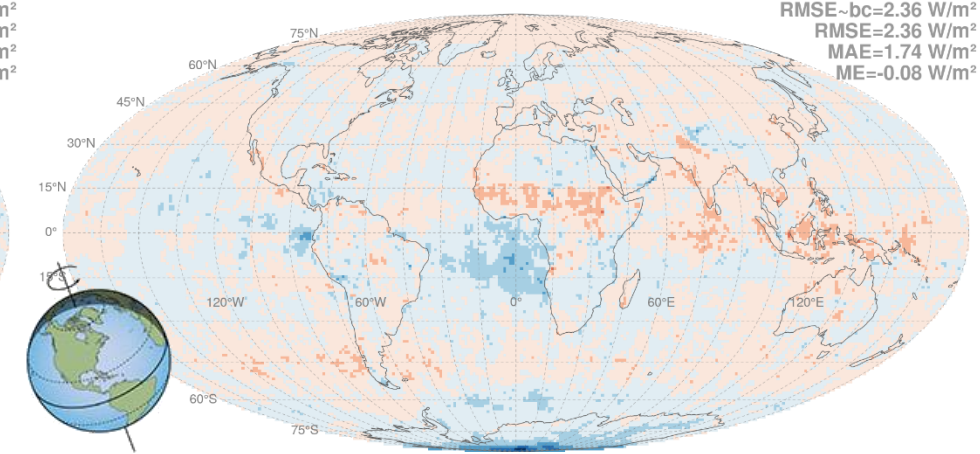
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200807)

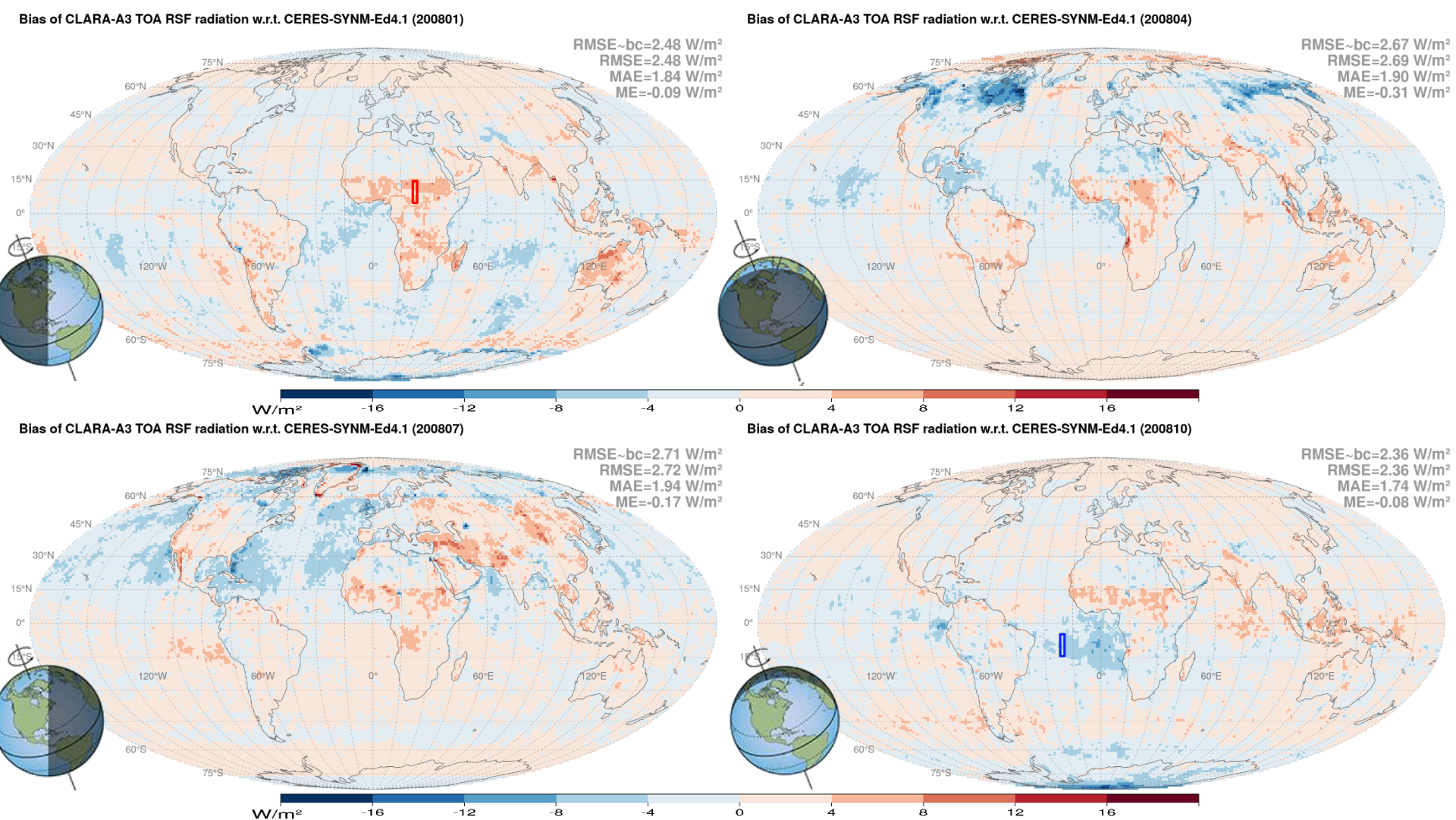
RMSE~bc=2.71 W/m²
RMSE=2.72 W/m²
MAE=1.94 W/m²
ME=-0.17 W/m²

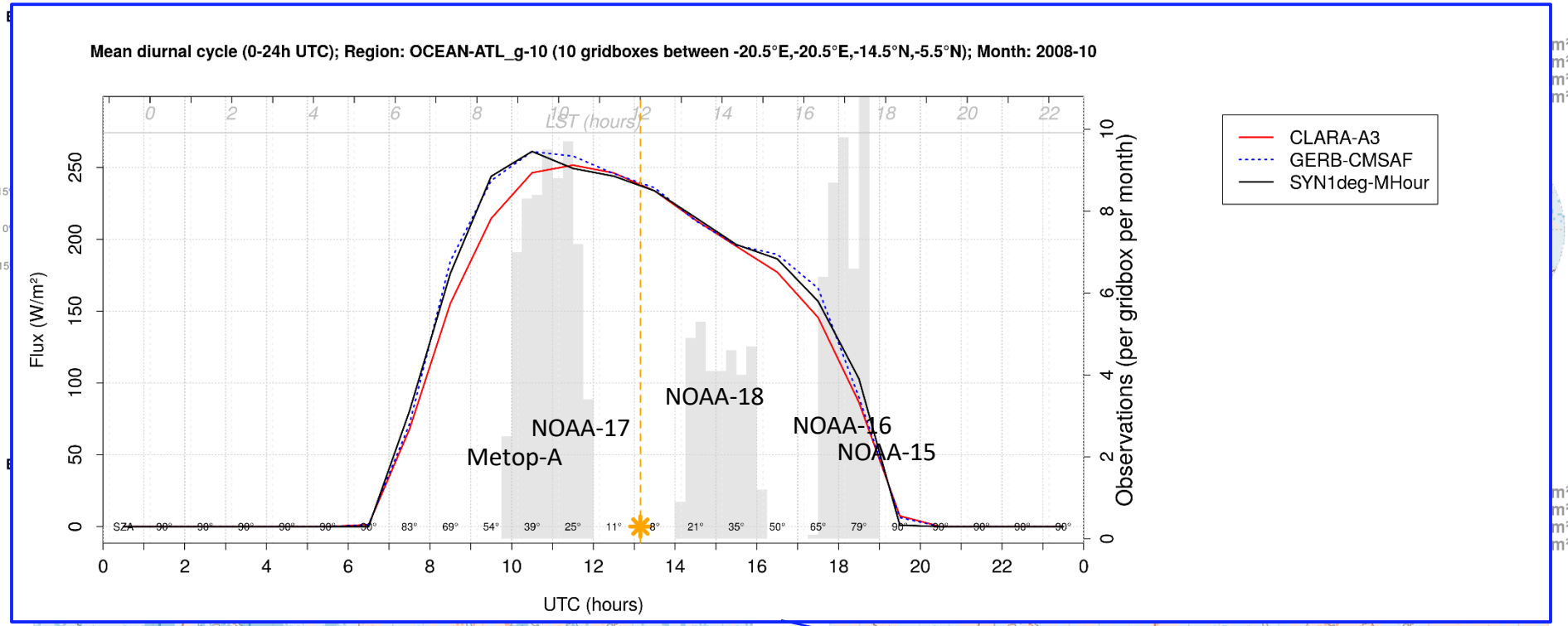


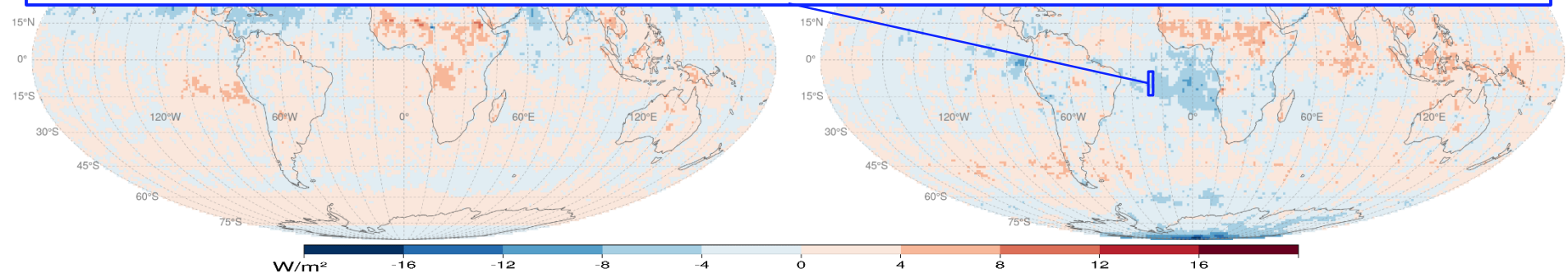
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200810)

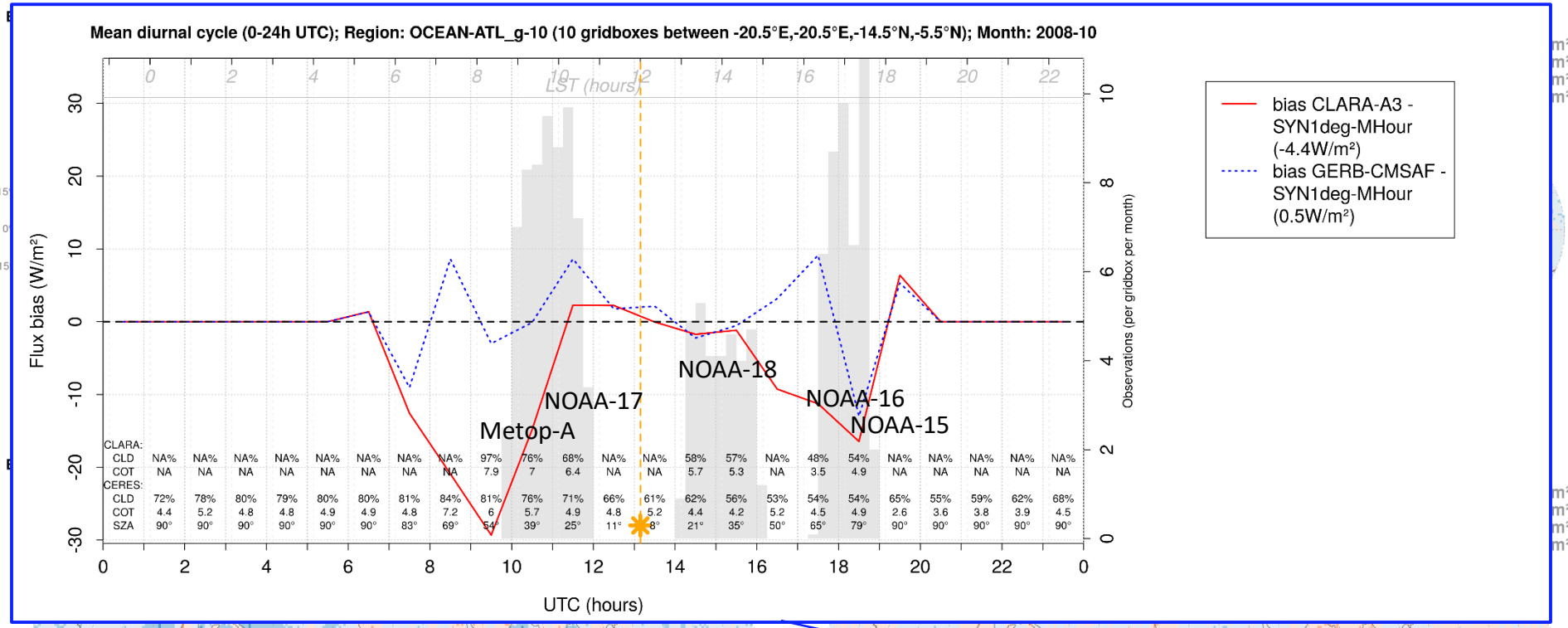
RMSE~bc=2.36 W/m²
RMSE=2.36 W/m²
MAE=1.74 W/m²
ME=-0.08 W/m²

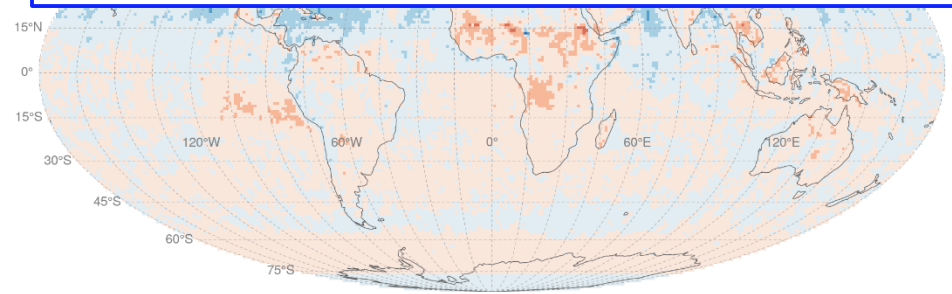


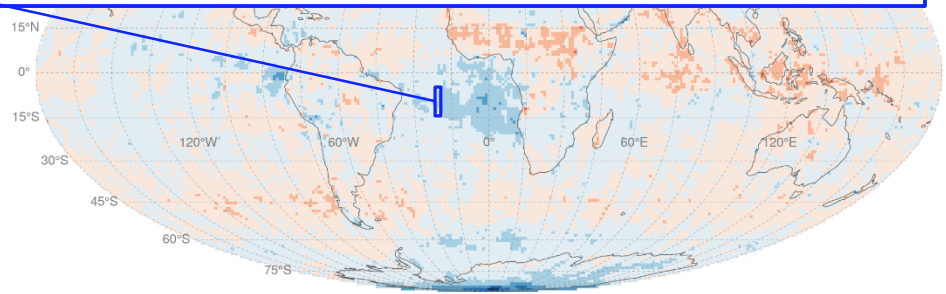

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)
RMSE~bc=2.48 W/m²
RMSE=2.48 W/m²
MAE=1.84 W/m²
ME=-0.09 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804)
RMSE~bc=2.67 W/m²
RMSE=2.69 W/m²
MAE=1.90 W/m²
ME=-0.31 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200807)
RMSE~bc=2.71 W/m²
RMSE=2.72 W/m²
MAE=1.94 W/m²
ME=-0.17 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200810)
RMSE~bc=2.36 W/m²
RMSE=2.36 W/m²
MAE=1.74 W/m²
ME=-0.08 W/m²
75°N
60°N
45°N
30°N
15°N
0°
15°S
60°S
75°S
120°W
60°W
0°
60°E
120°E
W/m²
-16
-12
-8
-4
0
4
8
12
16


Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_g-10 (10 gridboxes between -20.5°E,-20.5°E,-14.5°N,-5.5°N); Month: 2008-10
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
Metop-A
NOAA-17
NOAA-18
NOAA-16
NOAA-15
SZA

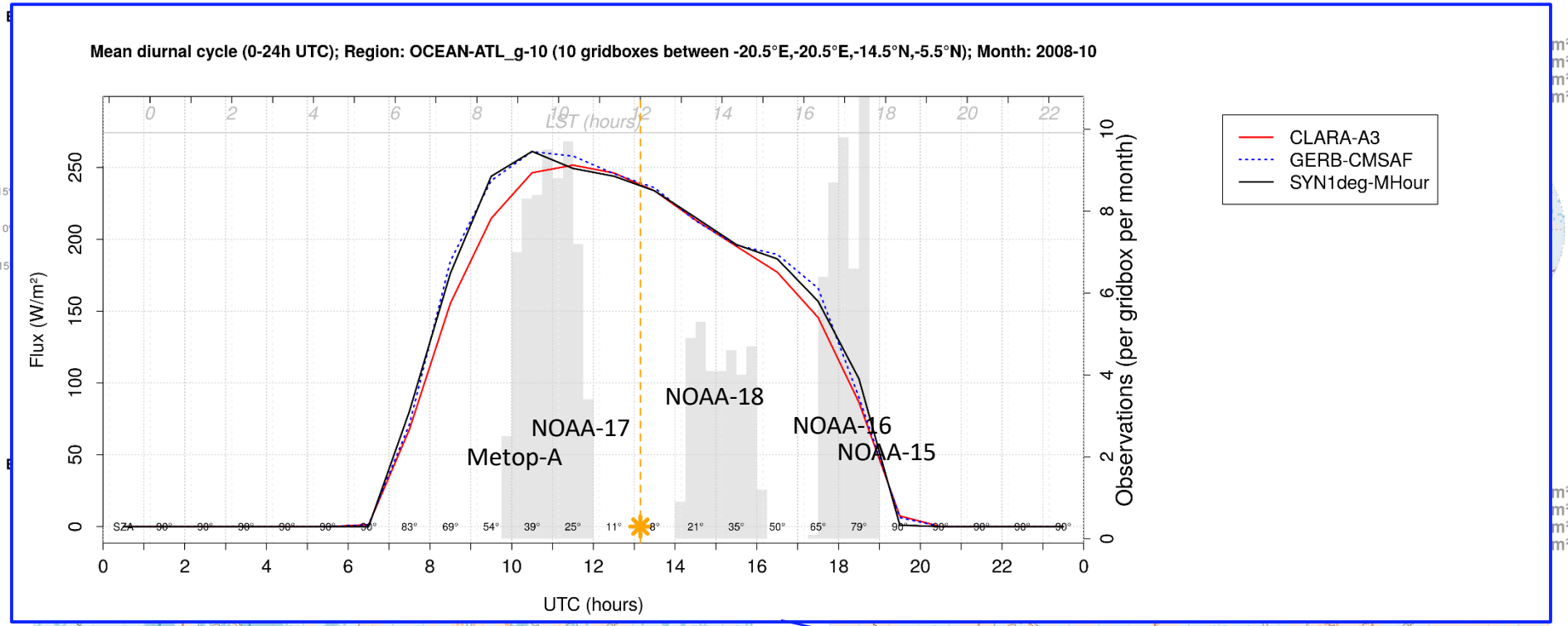

W/m²
-16
-12
-8
-4
0
4
8
12
16

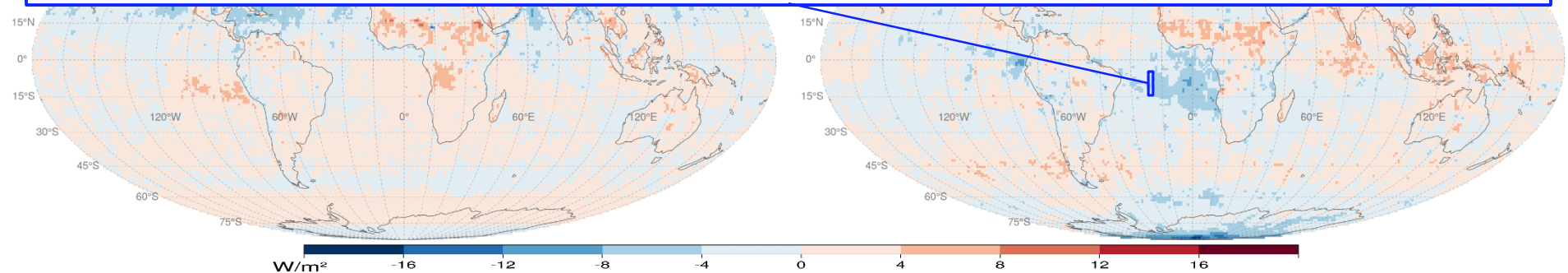


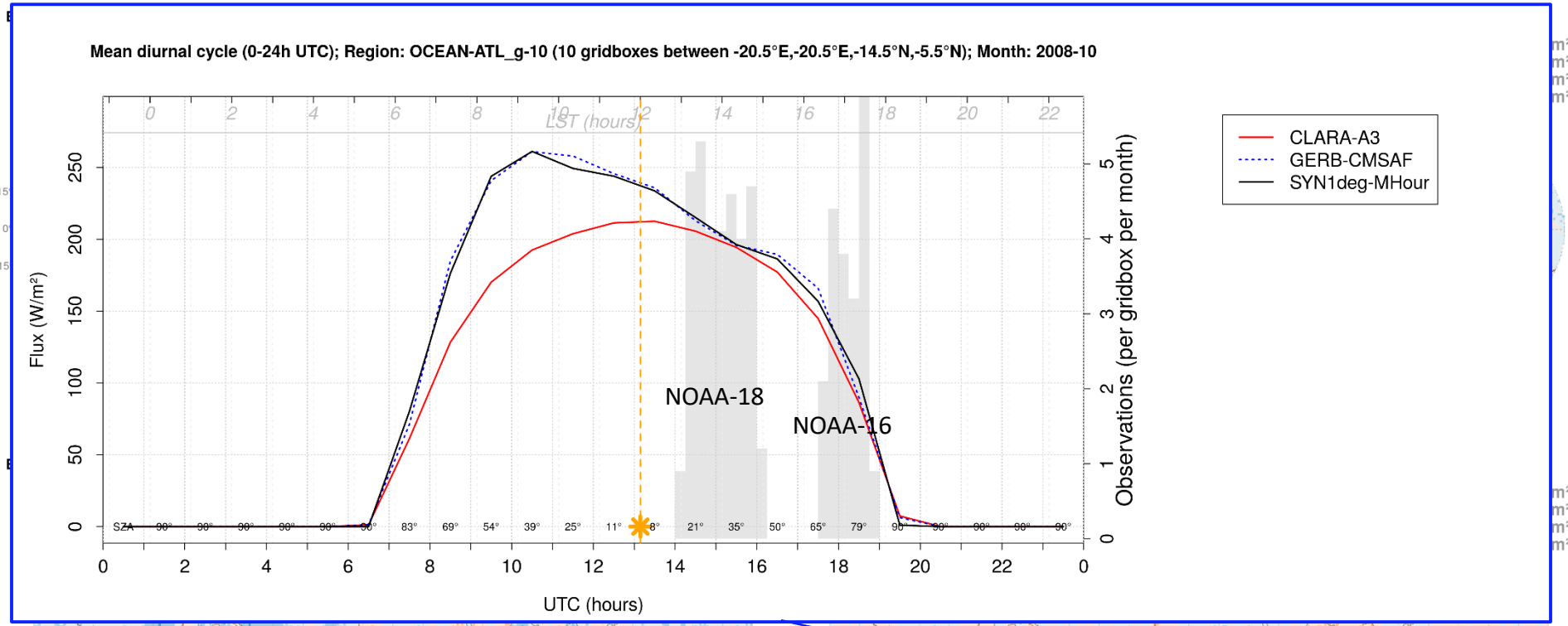


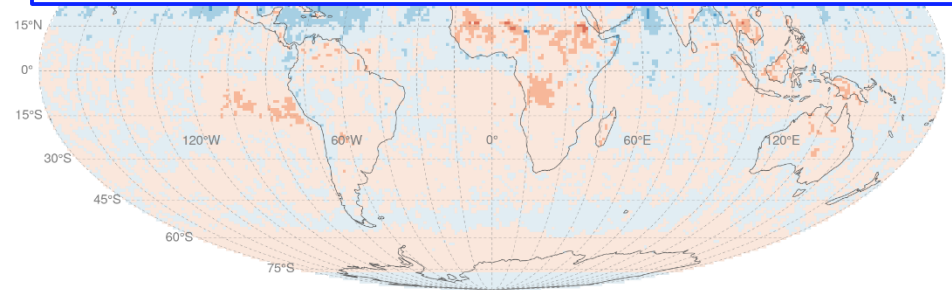


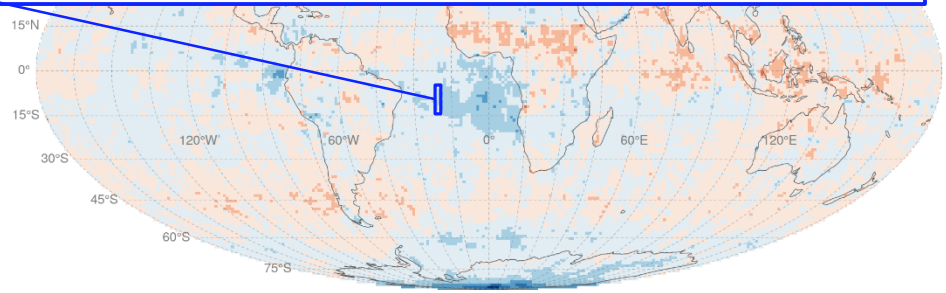
W/m² -16 -12 -8 -4 0 4 8 12 16

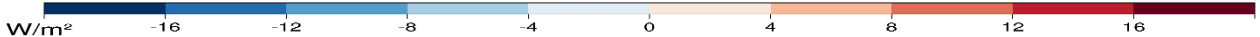

Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_g-10 (10 gridboxes between -20.5°E,-20.5°E,-14.5°N,-5.5°N); Month: 2008-10
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
Metop-A
NOAA-17
NOAA-18
NOAA-16
NOAA-15
SZA

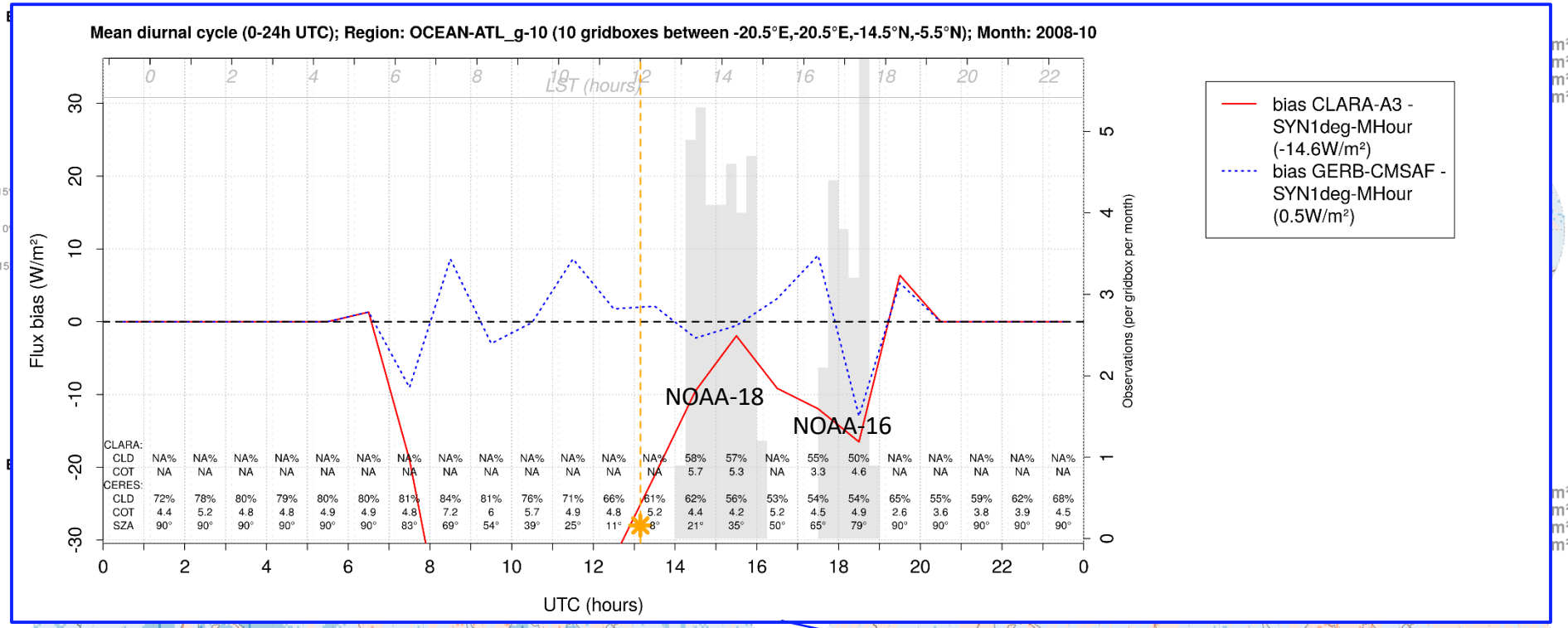

W/m²
-16
-12
-8
-4
0
4
8
12
16

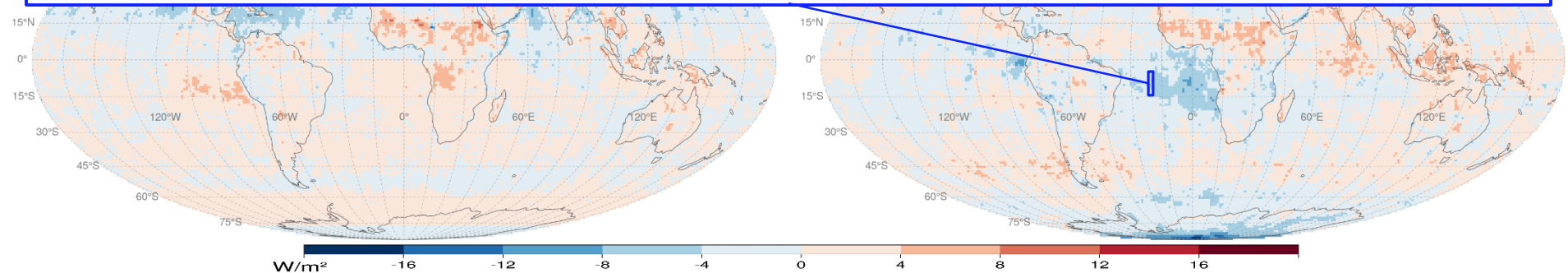

Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_g-10 (10 gridboxes between -20.5°E,-20.5°E,-14.5°N,-5.5°N); Month: 2008-10
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
NOAA-18
NOAA-16
SZA

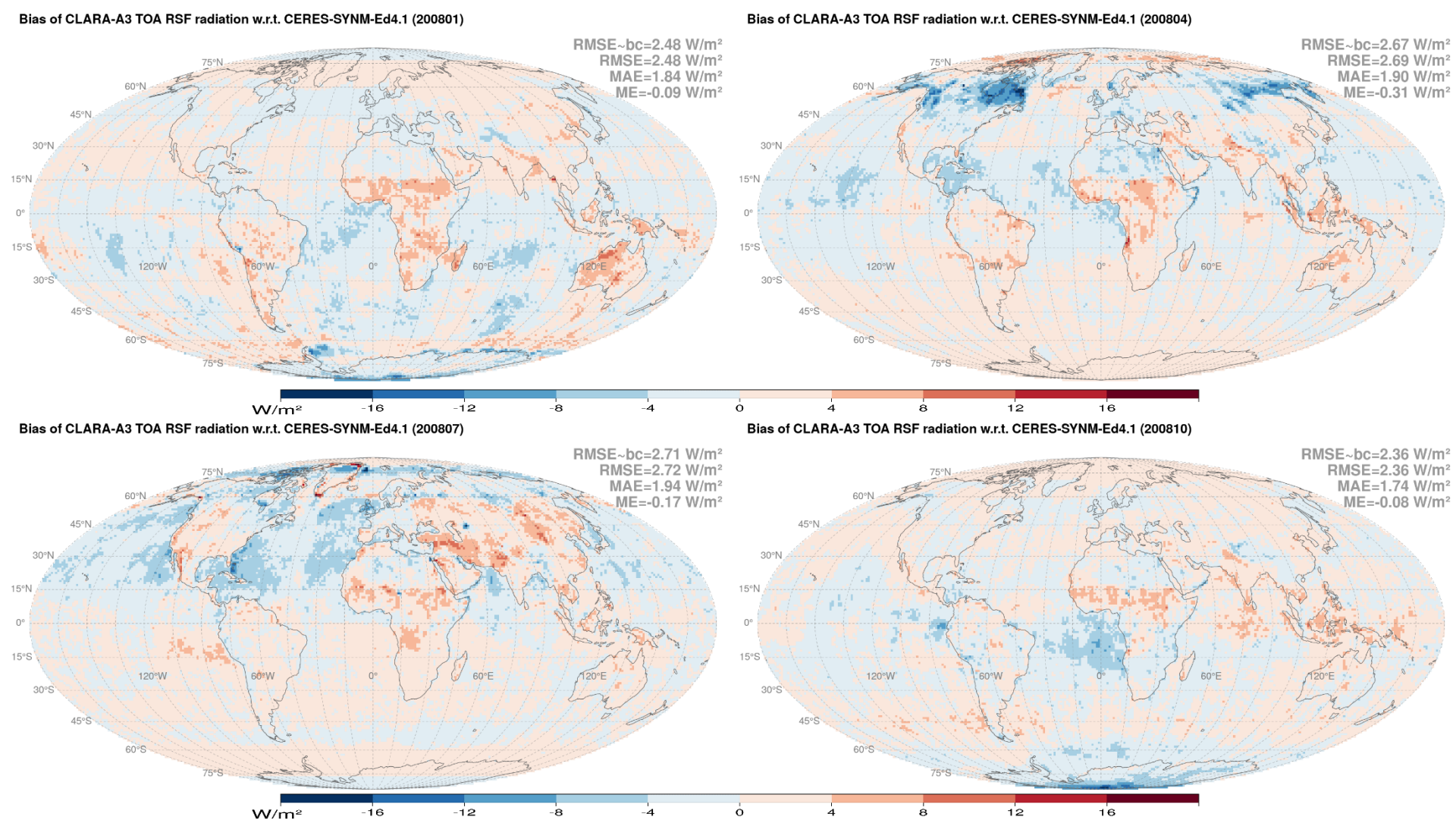

15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E


15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E


W/m²
-16
-12
-8
-4
0
4
8
12
16


Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_g-10 (10 gridboxes between -20.5°E,-20.5°E,-14.5°N,-5.5°N); Month: 2008-10
LST (hours)
Flux bias (W/m²)
Observations (per gridbox per month)
UTC (hours)
bias CLARA-A3 - SYN1deg-MHour (-14.6W/m²)
bias GERB-CMSAF - SYN1deg-MHour (0.5W/m²)
NOAA-18
NOAA-16
CLARA:
CLD NA% NA% NA% NA% NA% NA% NA% NA% NA% NA% NA% NA% NA% 58% 57% NA% 55% 50% NA% NA% NA% NA% NA%
COT NA NA NA NA NA NA NA NA NA NA NA NA NA 5.7 5.3 NA 3.3 4.6 NA NA NA NA NA
CERES:
CLD 72% 78% 80% 79% 80% 80% 81% 84% 81% 76% 71% 66% 61% 62% 56% 53% 54% 54% 65% 55% 59% 62% 68%
COT 4.4 5.2 4.8 4.8 4.9 4.9 4.8 7.2 6 5.7 4.9 4.8 5.2 4.4 4.2 5.2 4.5 4.9 2.6 3.6 3.8 3.9 4.5
SZA 90° 90° 90° 90° 90° 90° 83° 69° 54° 39° 25° 11° 8° 21° 35° 50° 65° 79° 90° 90° 90° 90° 90°


W/m²
-16
-12
-8
-4
0
4
8
12
16


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)
RMSE~bc=2.48 W/m²
RMSE=2.48 W/m²
MAE=1.84 W/m²
ME=-0.09 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804)
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MAE=1.90 W/m²
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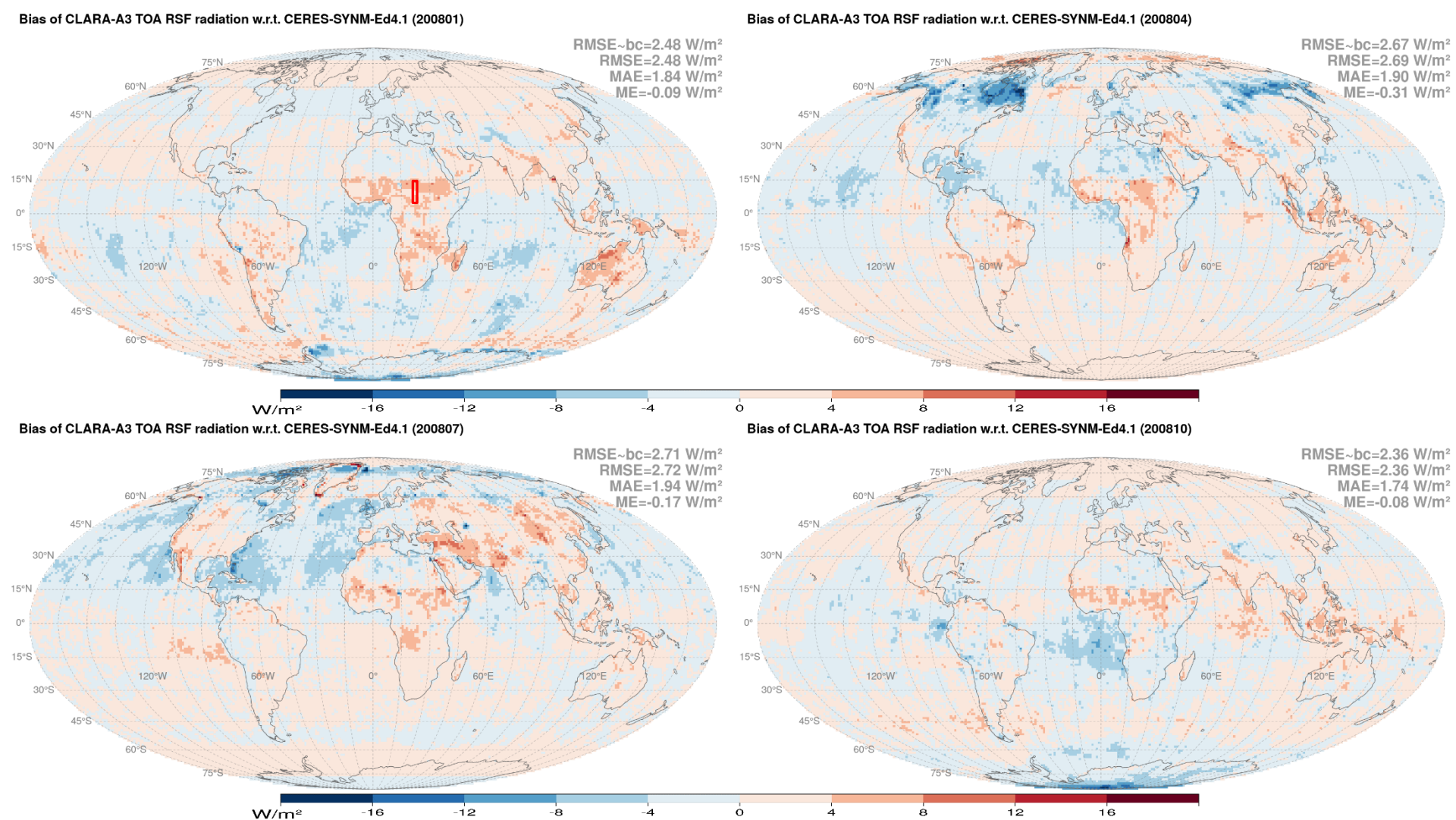
MAE=1.94 W/m²
ME=-0.17 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200810)
RMSE~bc=2.36 W/m²
RMSE=2.36 W/m²
MAE=1.74 W/m²
ME=-0.08 W/m²
75°N
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E
W/m²
-16
-12
-8
-4
0
4
8
12
16


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)
RMSE~bc=2.48 W/m²
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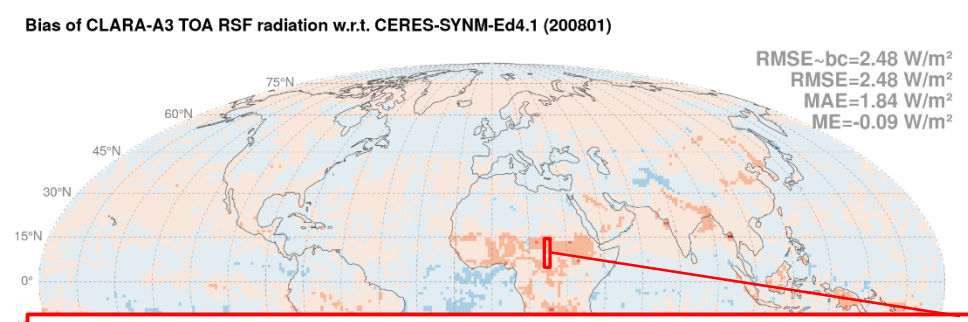
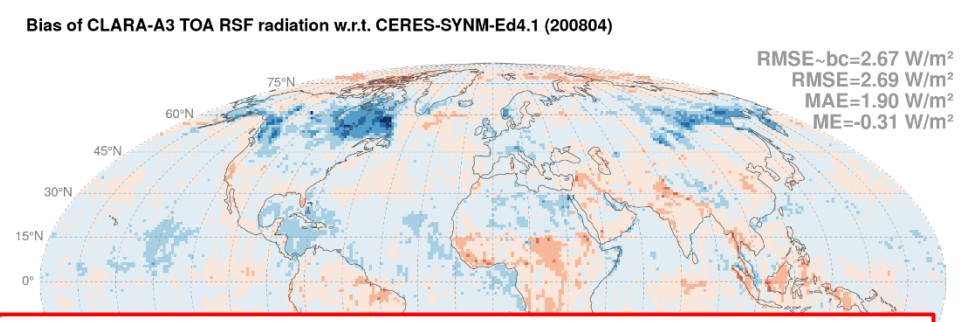
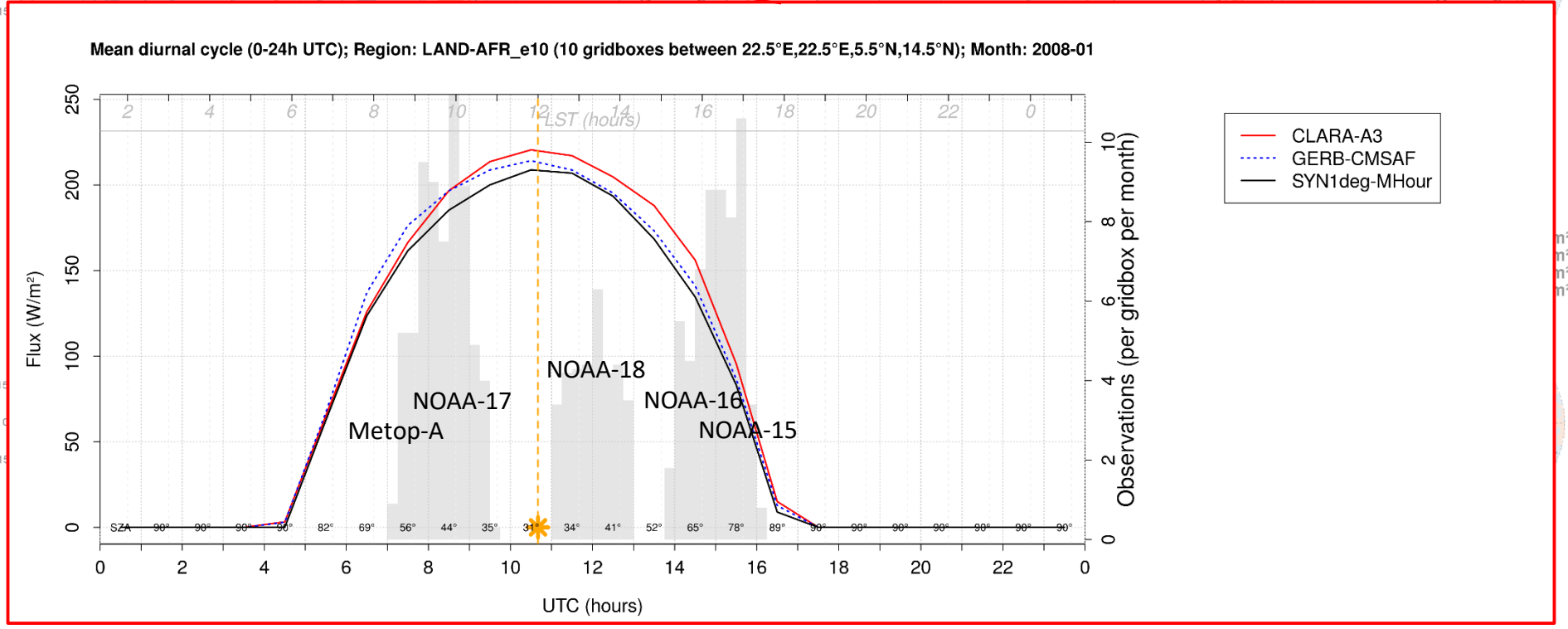
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200810)
RMSE~bc=2.36 W/m²
RMSE=2.36 W/m²
MAE=1.74 W/m²
ME=-0.08 W/m²
75°N
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E
W/m²
-16
-12
-8
-4
0
4
8
12
16

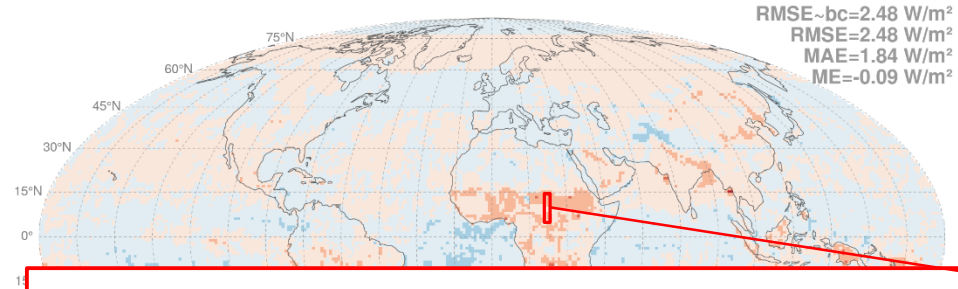

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)
RMSE~bc=2.48 W/m²
RMSE=2.48 W/m²
MAE=1.84 W/m²
ME=-0.09 W/m²
75°N
60°N
45°N
30°N
15°N
0°


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804)
RMSE~bc=2.67 W/m²
RMSE=2.69 W/m²
MAE=1.90 W/m²
ME=-0.31 W/m²
75°N
60°N
45°N
30°N
15°N
0°


Mean diurnal cycle (0-24h UTC); Region: LAND-AFR_e10 (10 gridboxes between 22.5°E,22.5°E,5.5°N,14.5°N); Month: 2008-01
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
NOAA-18
NOAA-17
NOAA-16
Metop-A
NOAA-15
SZA

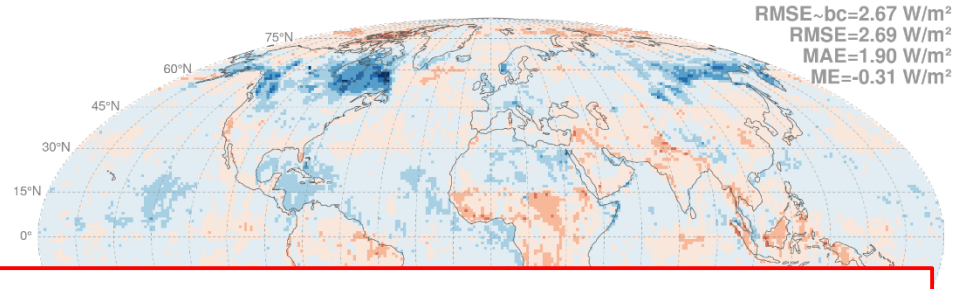
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)

RMSE~bc=2.48 W/m²
RMSE=2.48 W/m²
MAE=1.84 W/m²
ME=-0.09 W/m²

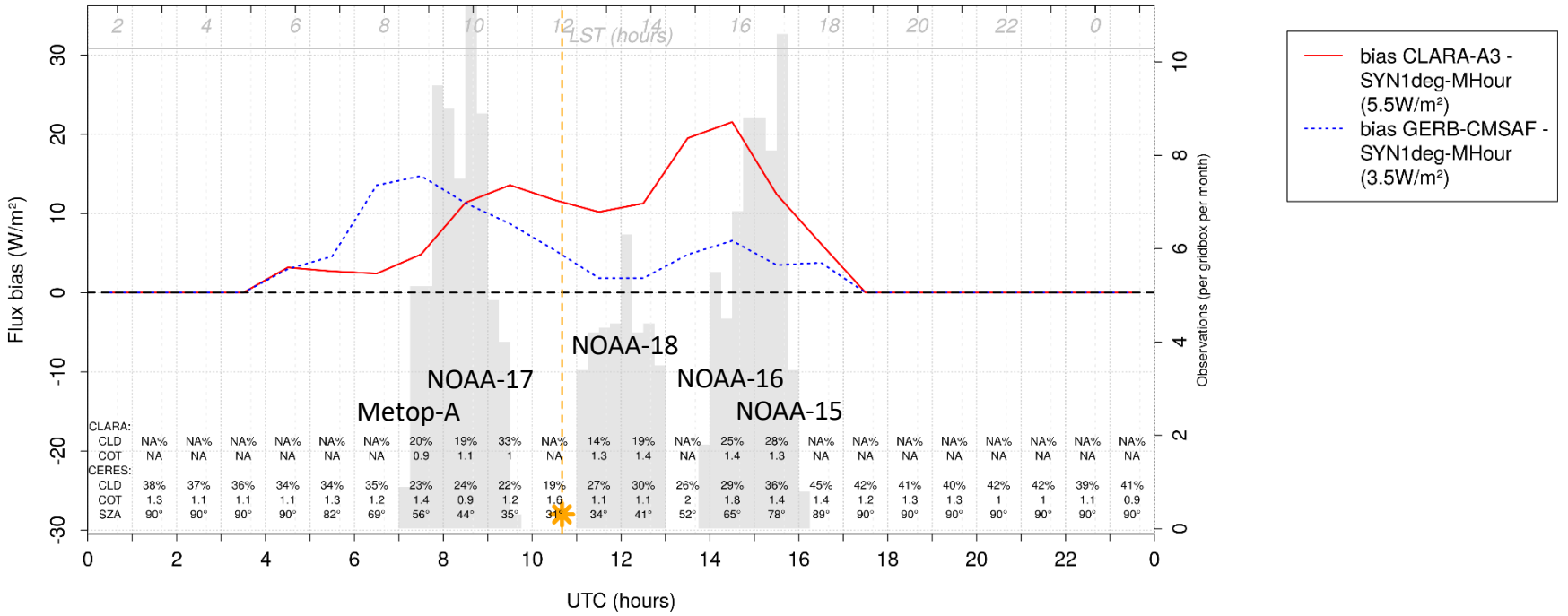


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804)

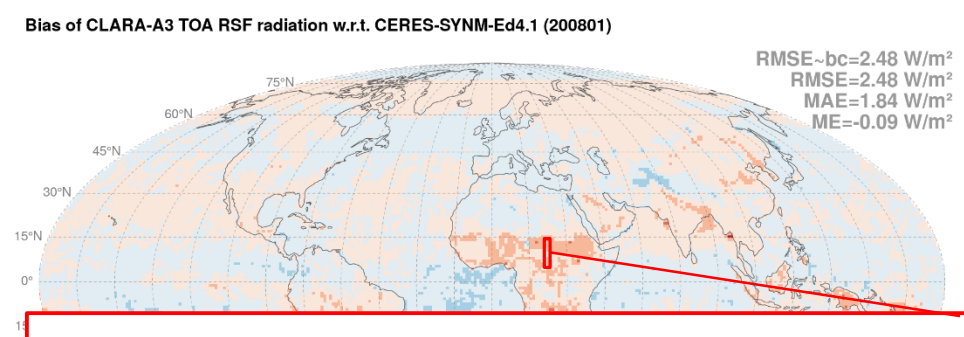
RMSE~bc=2.67 W/m²
RMSE=2.69 W/m²
MAE=1.90 W/m²
ME=-0.31 W/m²

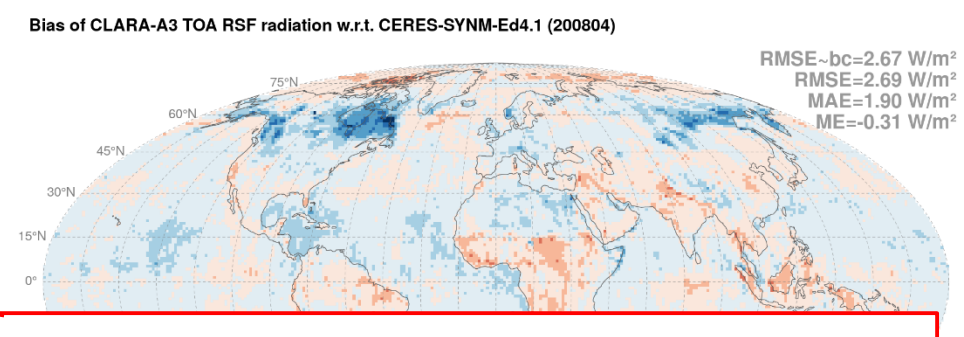


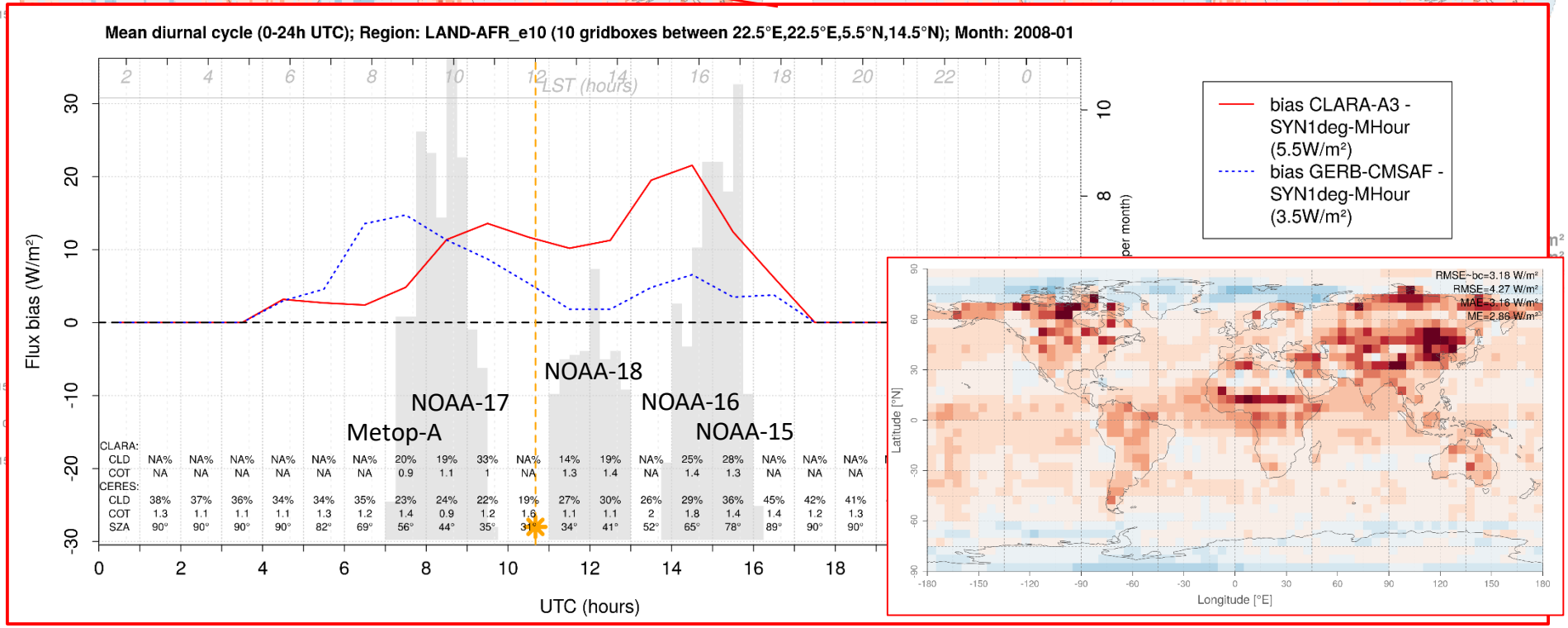
Mean diurnal cycle (0-24h UTC); Region: LAND-AFR_e10 (10 gridboxes between 22.5°E,22.5°E,5.5°N,14.5°N); Month: 2008-01

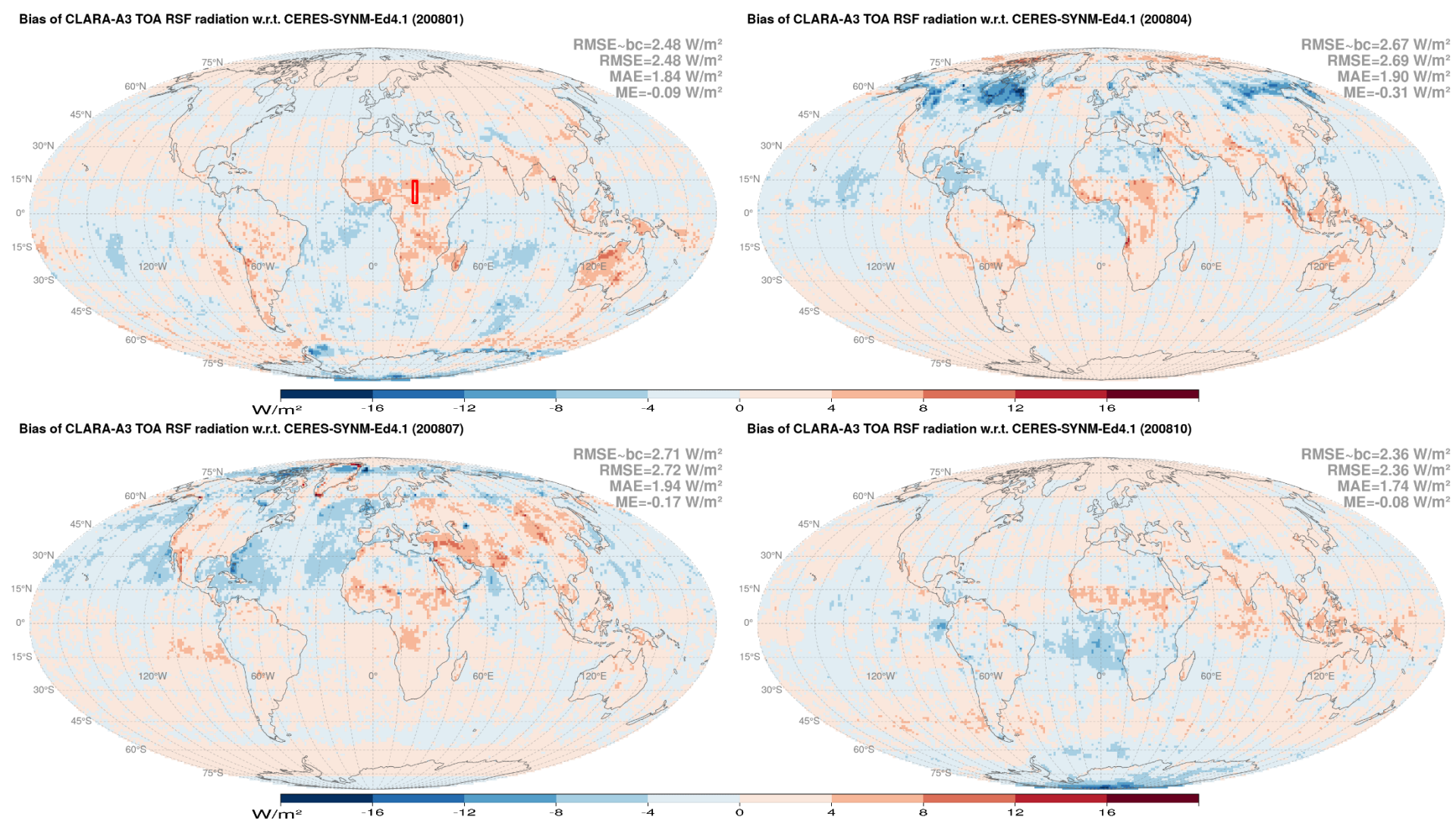


CLARA:																						
CLD	NA%	NA%	NA%	NA%	NA%	NA%	20%	19%	33%	NA%	14%	19%	NA%	25%	28%	NA%	NA%	NA%	NA%	NA%	NA%	NA%
COT	NA	NA	NA	NA	NA	NA	0.9	1.1	1	NA	1.3	1.4	NA	1.4	1.3	NA	NA	NA	NA	NA	NA	NA
CERES:																						
CLD	38%	37%	36%	34%	34%	35%	23%	24%	22%	19%	27%	30%	26%	29%	36%	45%	42%	41%	40%	42%	42%	39%	41%
COT	1.3	1.1	1.1	1.1	1.3	1.2	1.4	0.9	1.2	1.6	1.1	1.1	2	1.8	1.4	1.4	1.2	1.3	1.3	1	1	1.1	0.9
SZA	90°	90°	90°	90°	82°	69°	56°	44°	35°	31°	34°	41°	52°	65°	78°	89°	90°	90°	90°	90°	90°	90°	90°


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)
RMSE~bc=2.48 W/m²
RMSE=2.48 W/m²
MAE=1.84 W/m²
ME=-0.09 W/m²
75°N
60°N
45°N
30°N
15°N
0°

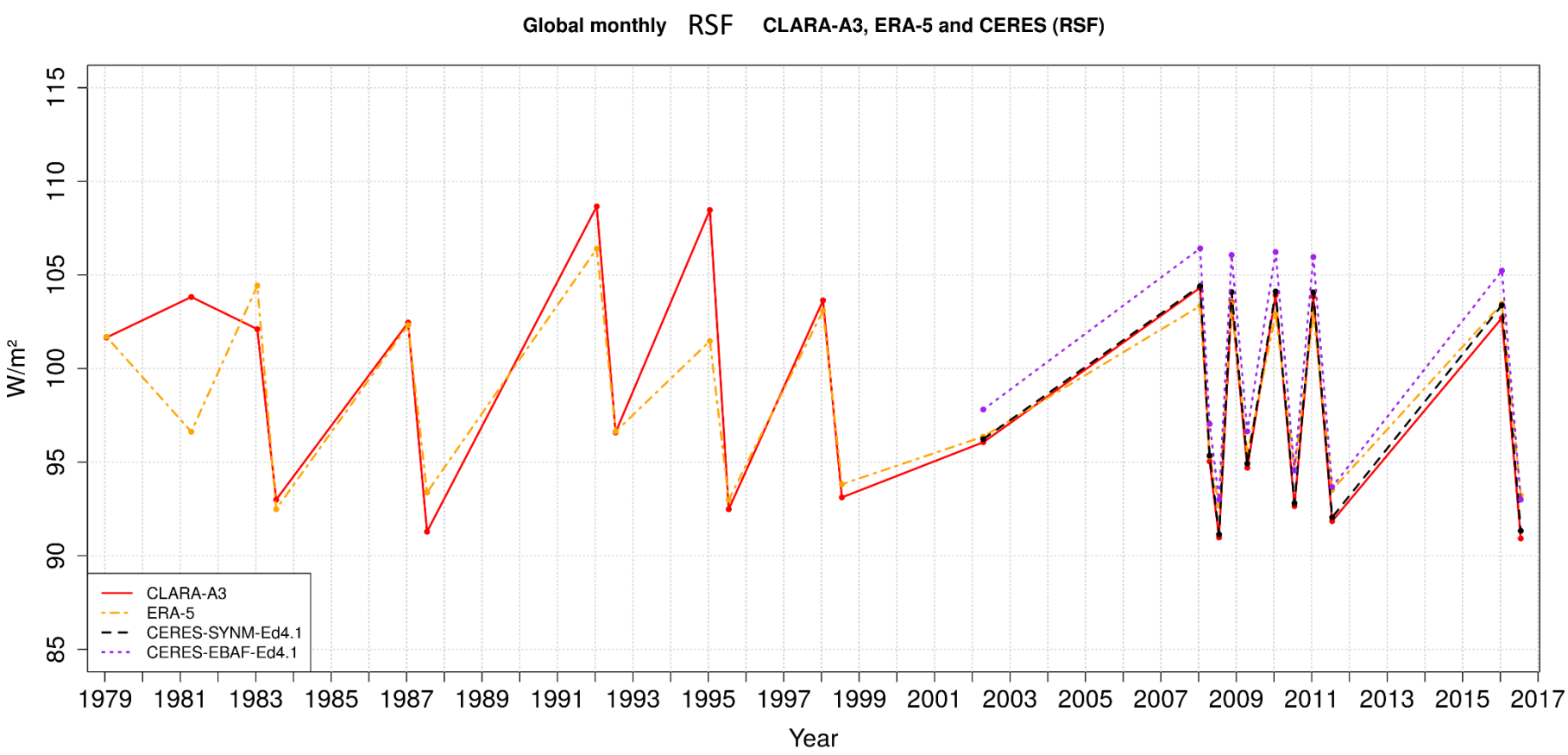

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804)
RMSE~bc=2.67 W/m²
RMSE=2.69 W/m²
MAE=1.90 W/m²
ME=-0.31 W/m²
75°N
60°N
45°N
30°N
15°N
0°


Mean diurnal cycle (0-24h UTC); Region: LAND-AFR_e10 (10 gridboxes between 22.5°E,22.5°E,5.5°N,14.5°N); Month: 2008-01
LST (hours)
2 4 6 8 10 12 14 16 18 20 22 0
Flux bias (W/m²)
30 20 10 0 -10 -20 -30
UTC (hours)
0 2 4 6 8 10 12 14 16 18
10
8
per month)
bias CLARA-A3 - SYN1deg-MHour (5.5W/m²)
bias GERB-CMSAF - SYN1deg-MHour (3.5W/m²)
NOAA-18
NOAA-17
NOAA-16
Metop-A
NOAA-15
CLARA:
CLD NA% NA% NA% NA% NA% NA% 20% 19% 33% NA% 14% 19% NA% 25% 28% NA% NA% NA%
COT NA NA NA NA NA NA 0.9 1.1 1 NA 1.3 1.4 NA 1.4 1.3 NA NA NA
CERES:
CLD 38% 37% 36% 34% 34% 35% 23% 24% 22% 19% 27% 30% 26% 29% 36% 45% 42% 41%
COT 1.3 1.1 1.1 1.1 1.3 1.2 1.4 0.9 1.2 1.6 1.1 1.1 2 1.8 1.4 1.4 1.2 1.3
SZA 90° 90° 90° 90° 82° 69° 56° 44° 35° 31° 34° 41° 52° 65° 78° 89° 90° 90°
RMSE~bc=3.18 W/m²
RMSE=4.27 W/m²
MAE=3.16 W/m²
ME=2.86 W/m²
Latitude [°N]
90 60 30 0 -30 -60 -90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
Longitude [°E]

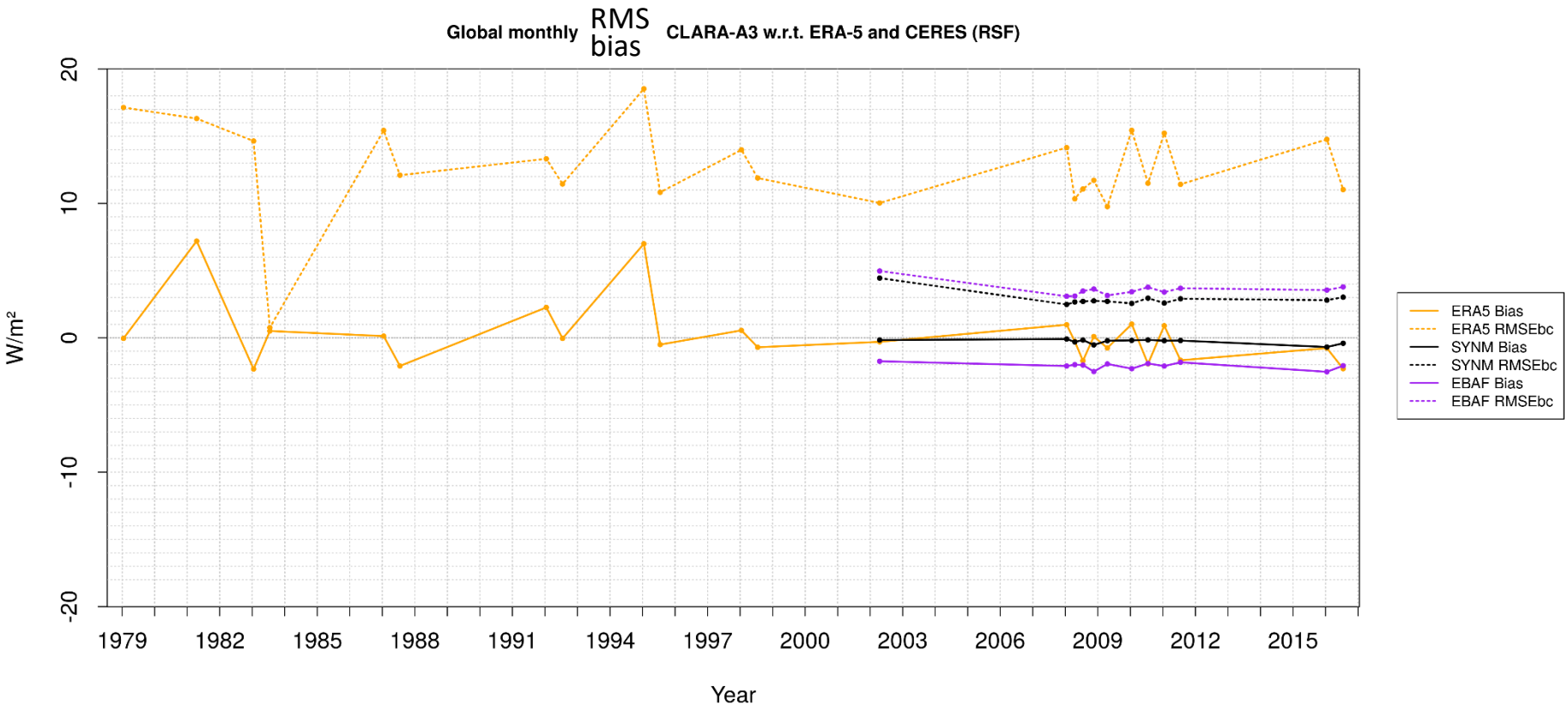

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801)
RMSE~bc=2.48 W/m²
RMSE=2.48 W/m²
MAE=1.84 W/m²
ME=-0.09 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804)
RMSE~bc=2.67 W/m²
RMSE=2.69 W/m²
MAE=1.90 W/m²
ME=-0.31 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200807)
RMSE~bc=2.71 W/m²
RMSE=2.72 W/m²
MAE=1.94 W/m²
ME=-0.17 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200810)
RMSE~bc=2.36 W/m²
RMSE=2.36 W/m²
MAE=1.74 W/m²
ME=-0.08 W/m²
75°N
60°N
45°N
30°N
15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E
W/m²
-16
-12
-8
-4
0
4
8
12
16

2.3. Validation longterm timeseries

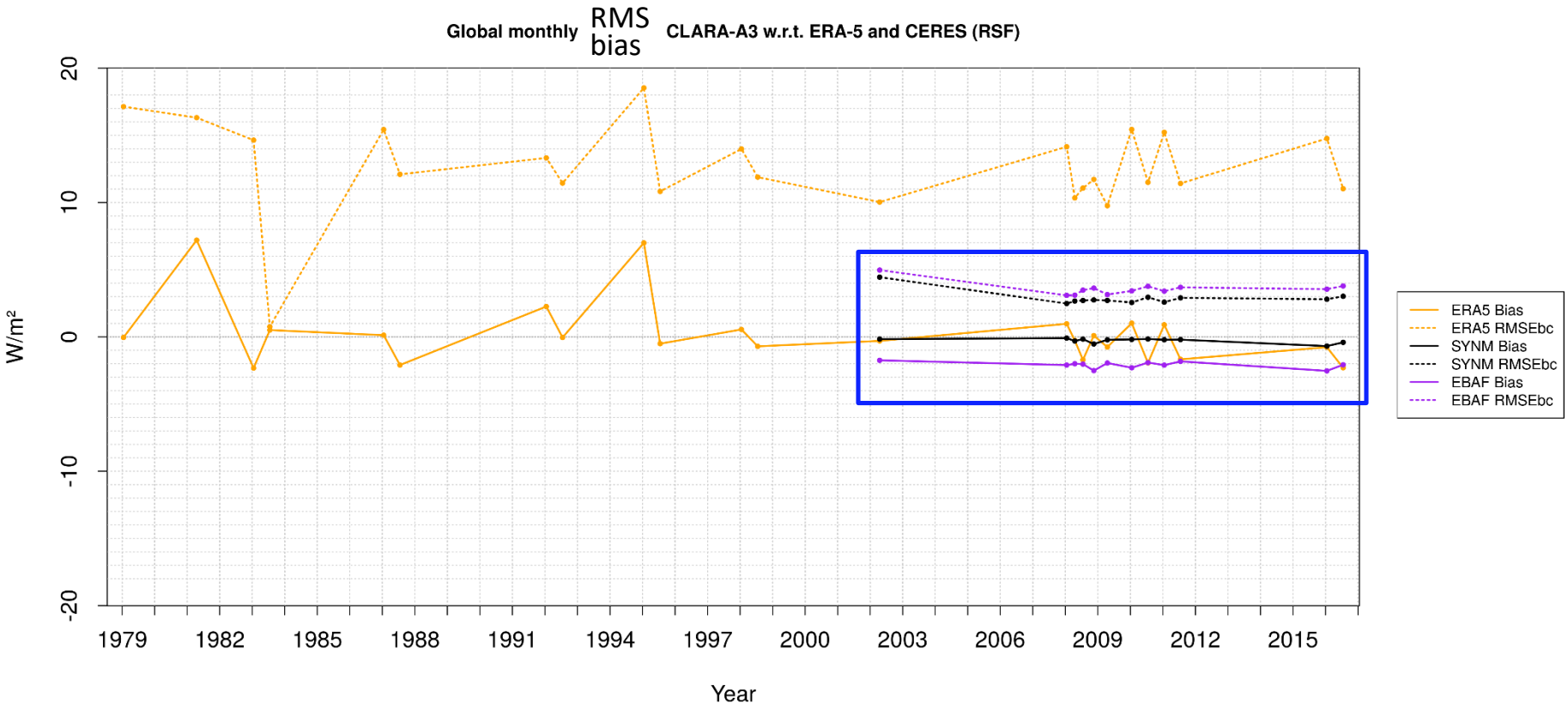
2.3. Validation longterm timeseries



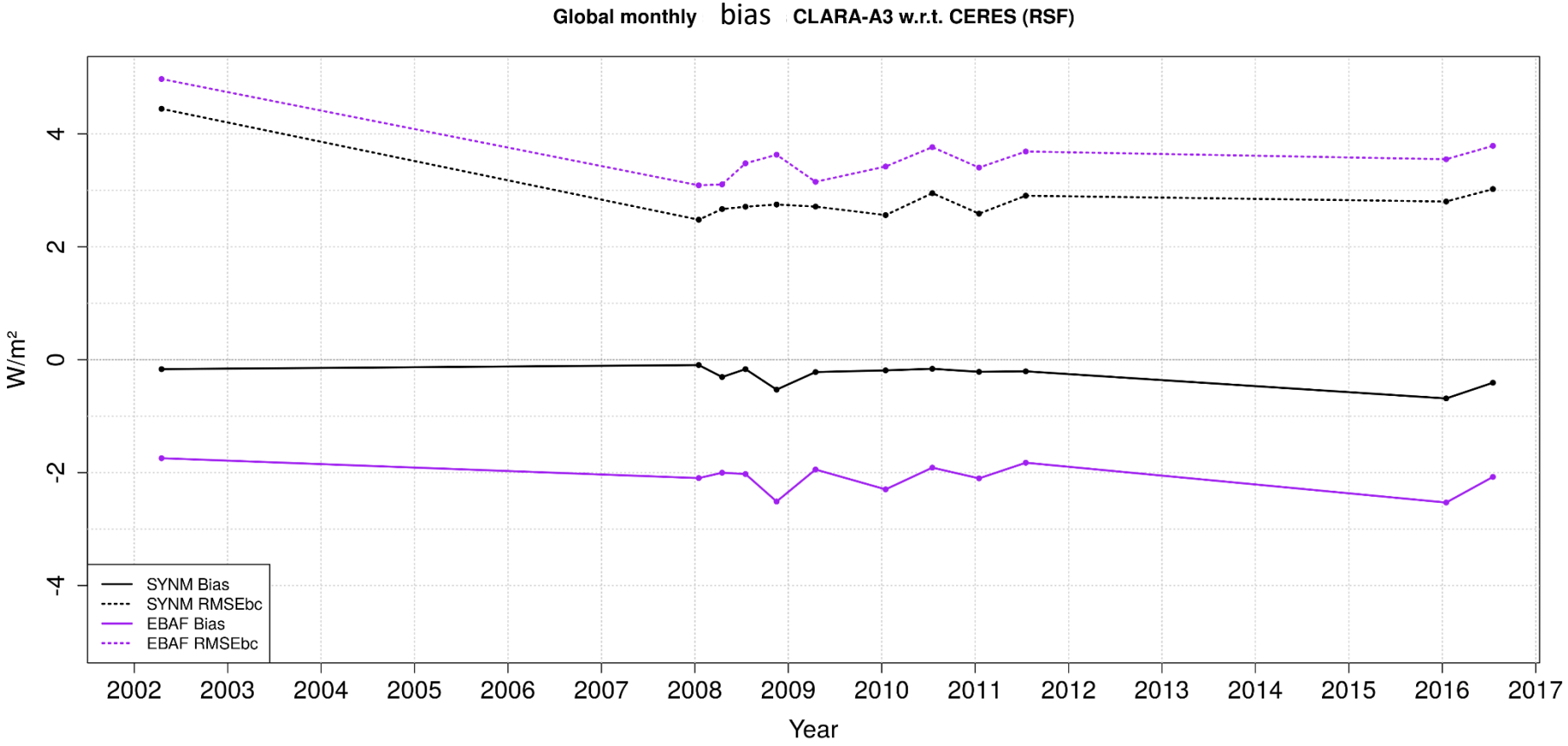
2.3. Validation longterm timeseries



2.3. Validation longterm timeseries



2.3. Validation longterm timeseries



EUMETSAT CM SAF

CCLRC - DFBO - DIFA - GKSS - Hadley Centre GERB Imperial College - RMIB - University of Leicester

RMI Royal Meteorological Institute Belgium

Thanks for your attention!

<tom.akkermans@meteo.be>

Extra slides

1. Introduction

- 1.1. CLARA-A3 TOA reflected solar flux ('RSF')
- **1.2. improvements/changes during last year**

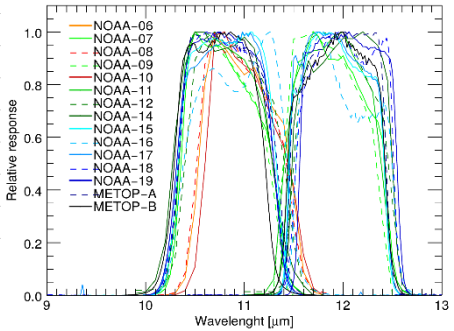
2. Validation results:

- 2.1. Instantaneous RSF (level-2)
- 2.2. Daily and monthly mean RSF (level-3) +Monthly mean diurnal cycle
- 2.3. Long term time series, stability

1. Introduction

- **1.2. Additions/improvements implemented during last year:**
  - Spectral response corrections:

AVHRR	Channel 1		Channel 2		Channel 4		Channel 5	
satellite	slope	offset	slope	offset	slope	offset	slope	offset
tirosn	1.023	-1.449	1.006	0.085	1.003	-0.540	1.000	0.000
noaa5	1.009	-0.174	1.011	-0.102	0.999	0.236	1.000	0.000
noaa6	1.012	-0.027	1.003	-0.052	0.999	0.300	1.000	0.000
noaa7	1.009	-0.036	1.007	-0.007	1.000	-0.198	0.991	1.991
noaa8	1.010	-0.009	1.003	-0.048	0.999	0.201	1.000	0.000



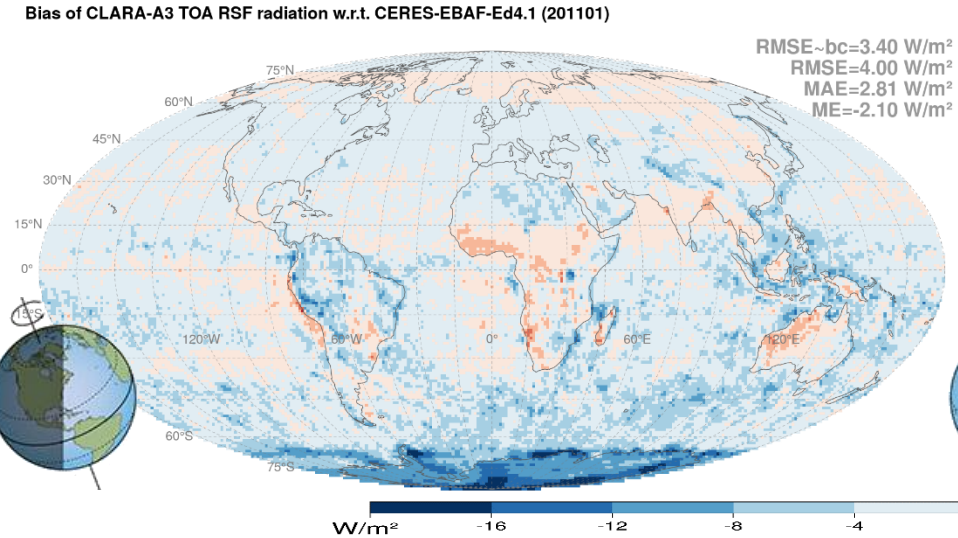
  - ADM interpolation between SZA,VZA,RAA bins now done on fluxes, not on anisotropic factors.
  - ADM interpolation bias correction (Loeb et al. 2003):

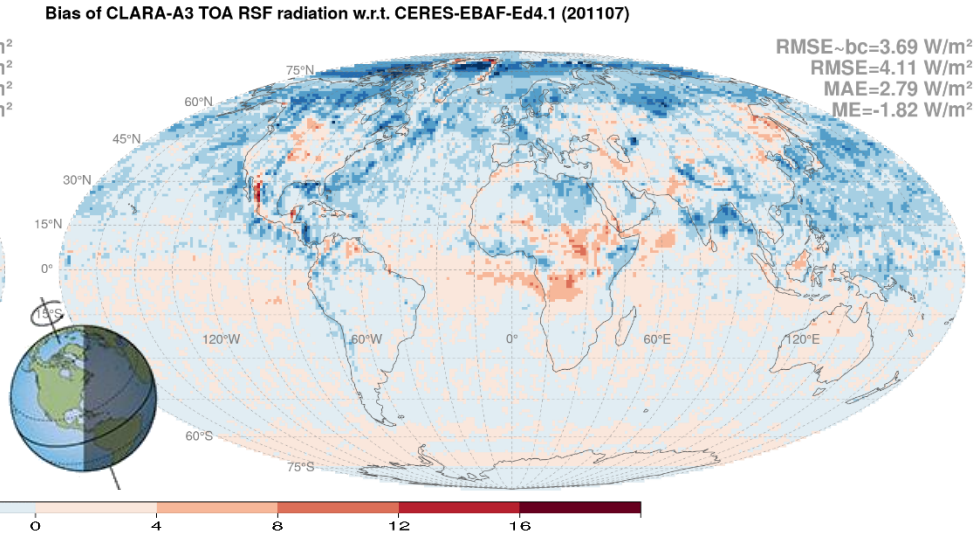
$$\hat{F}'(\theta_o,\ \theta,\ \phi;\ h_{\mathrm{sfc}}) = \frac{\pi I(\theta_o,\ \theta,\ \phi;\ h_{\mathrm{sfc}})}{\tilde{R}_j(\theta_o,\ \theta,\ \phi;\ h_{\mathrm{sfc}})} + \delta F_j(\theta_o,\ \theta,\ \phi;\ h_{\mathrm{sfc}}), \quad (16)$$

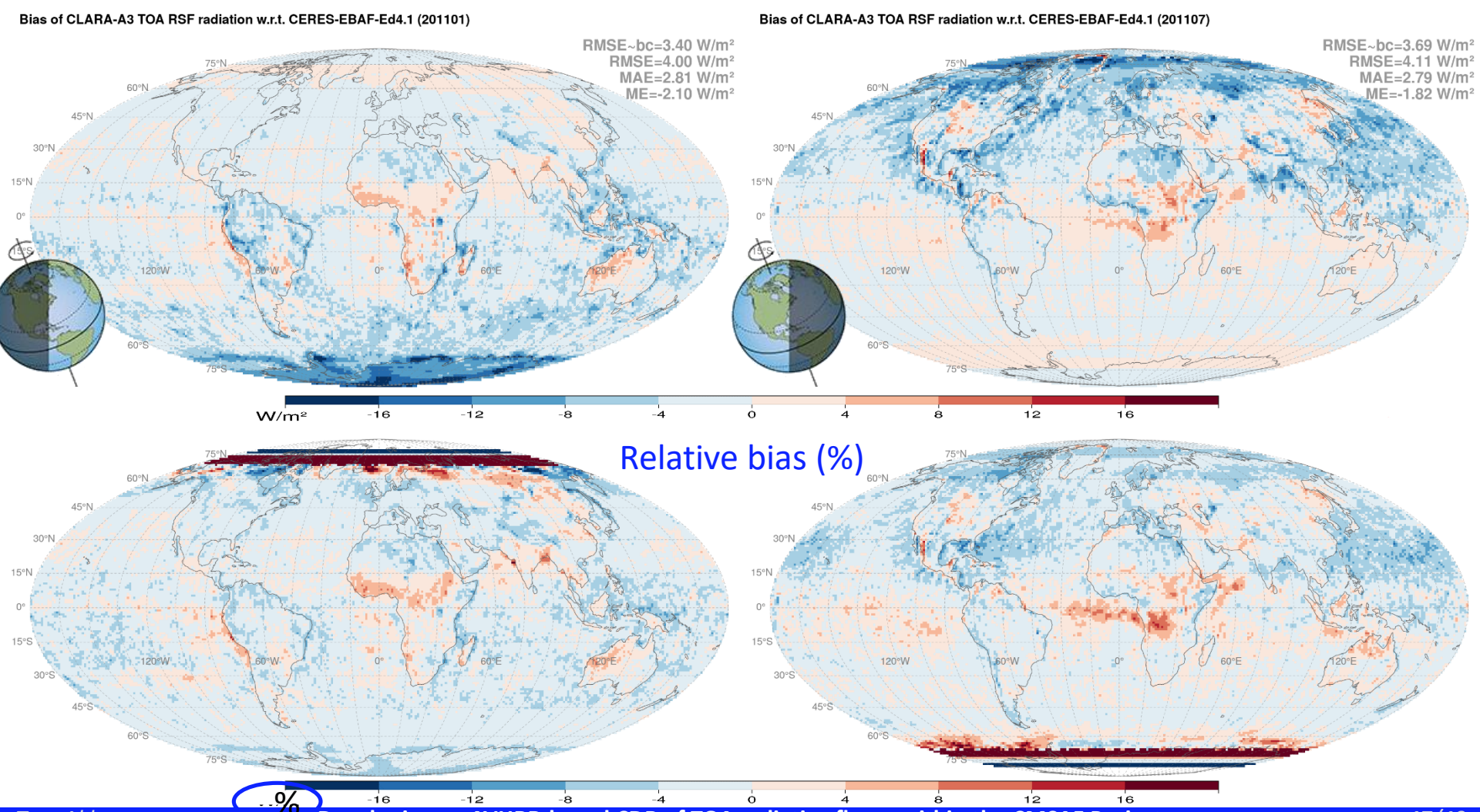
  - ADM: weighted scene types from discretized bins with cloudcover and COT:
    - E.g. cloud cover is 20%, so the anisotropic factor is calculated as weighted mean from anisotropic factors corresponding to the discretized scenetypes with respectively 0-25% and 25-50% cloud cover.

2.2. Validation daily/monthly L3

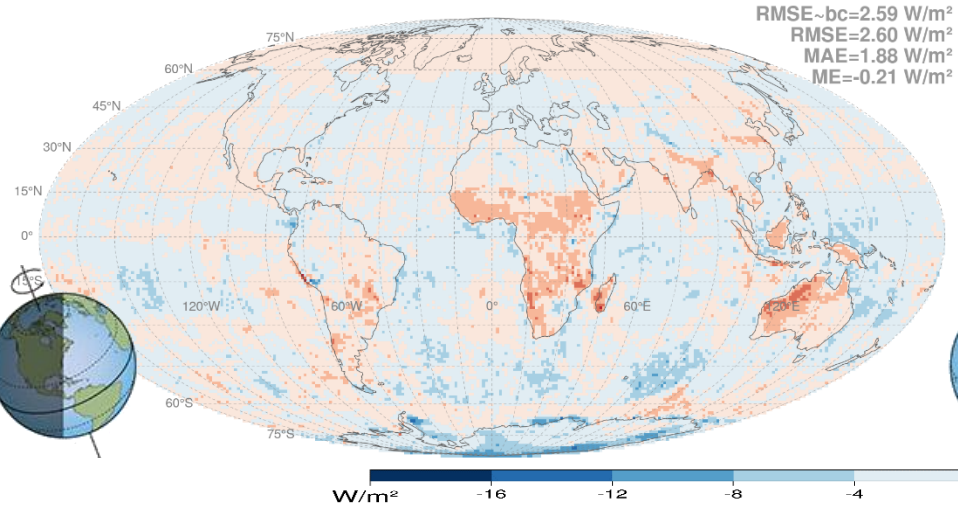
- 2011


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (201101)
RMSE~bc=3.40 W/m²
RMSE=4.00 W/m²
MAE=2.81 W/m²
ME=-2.10 W/m²
75°N
60°N
45°N
30°N
15°N
0°
15°S
60°S
75°S
120°W
60°W
0°
60°E
120°E
W/m²
-16
-12
-8
-4
0
4
8
12
16

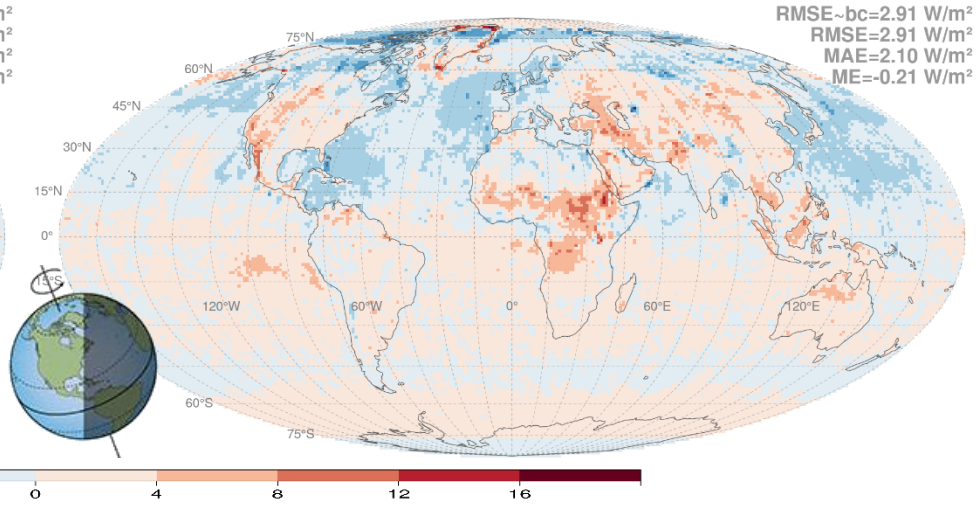

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (201107)
RMSE~bc=3.69 W/m²
RMSE=4.11 W/m²
MAE=2.79 W/m²
ME=-1.82 W/m²
75°N
60°N
45°N
30°N
15°N
0°
15°S
60°S
75°S
120°W
60°W
0°
60°E
120°E

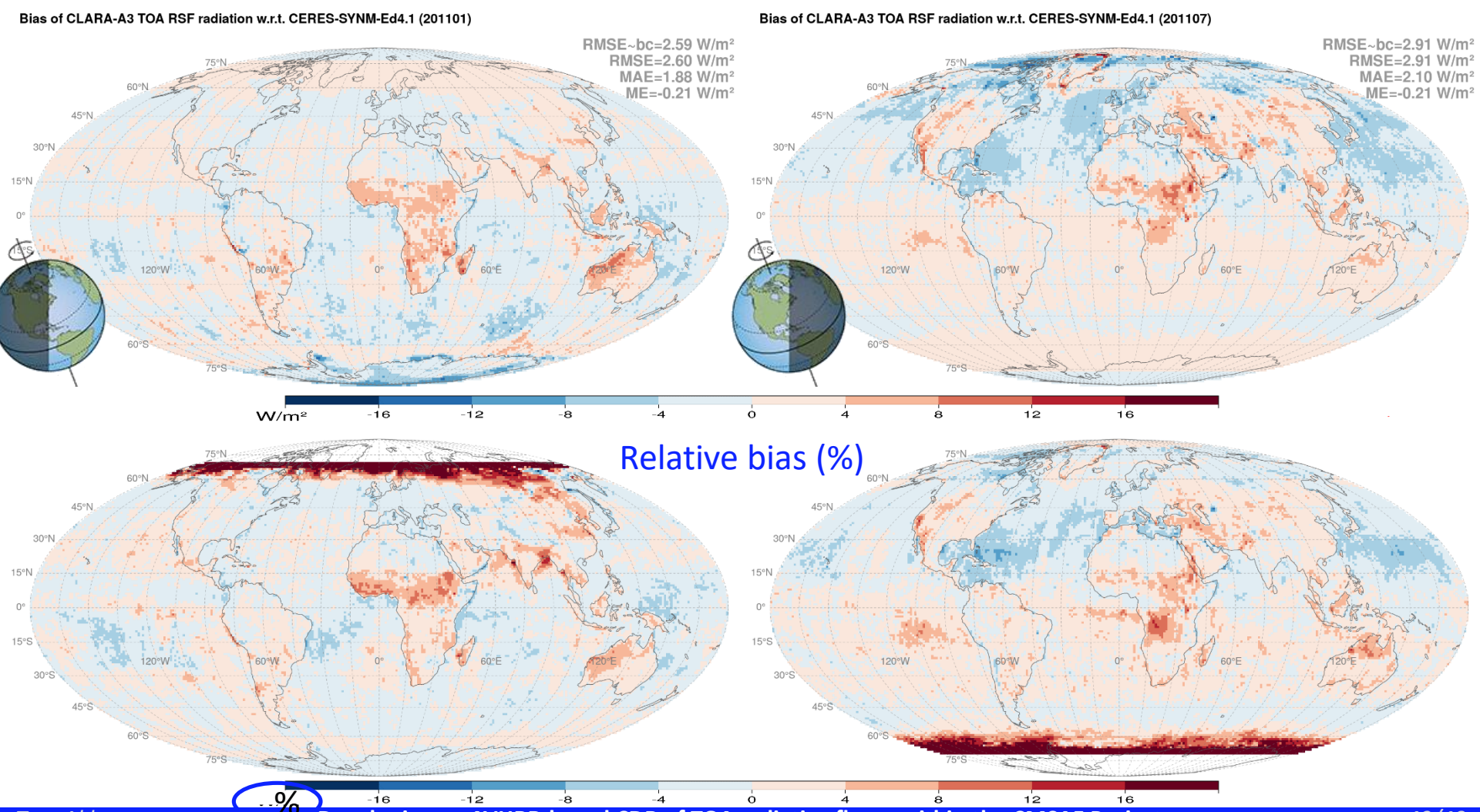

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (201101)
RMSE~bc=3.40 W/m²
RMSE=4.00 W/m²
MAE=2.81 W/m²
ME=-2.10 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-EBAF-Ed4.1 (201107)
RMSE~bc=3.69 W/m²
RMSE=4.11 W/m²
MAE=2.79 W/m²
ME=-1.82 W/m²
W/m²
-16 -12 -8 -4 0 4 8 12 16
Relative bias (%)
%
-16 -12 -8 -4 0 4 8 12 16

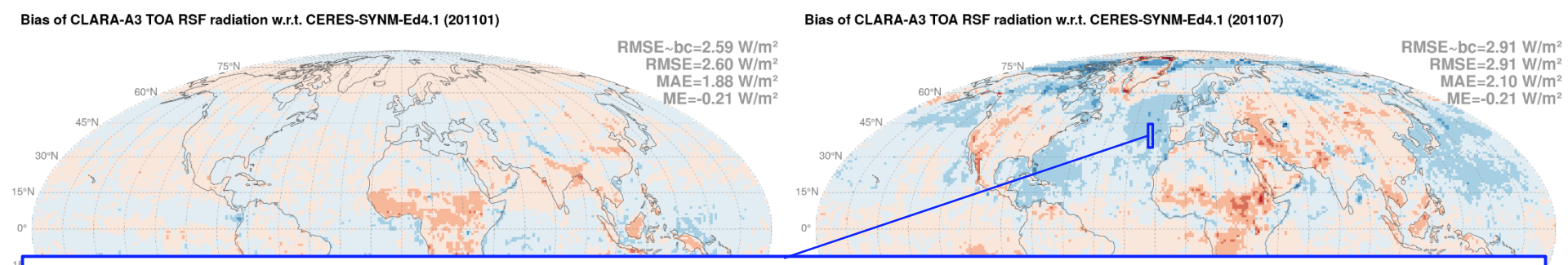
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)



Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)




Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
RMSE~bc=2.59 W/m²
RMSE=2.60 W/m²
MAE=1.88 W/m²
ME=-0.21 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²
W/m²
-16
-12
-8
-4
0
4
8
12
16
Relative bias (%)
%
-16
-12
-8
-4
0
4
8
12
16


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
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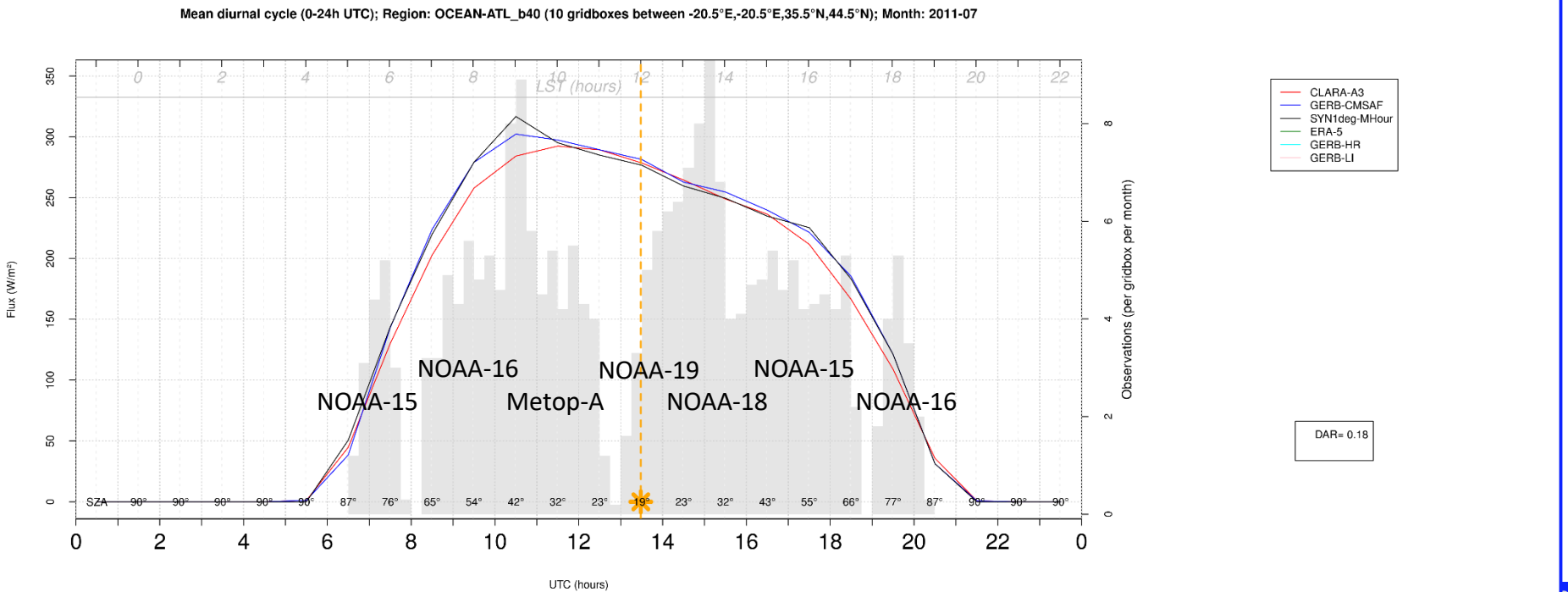
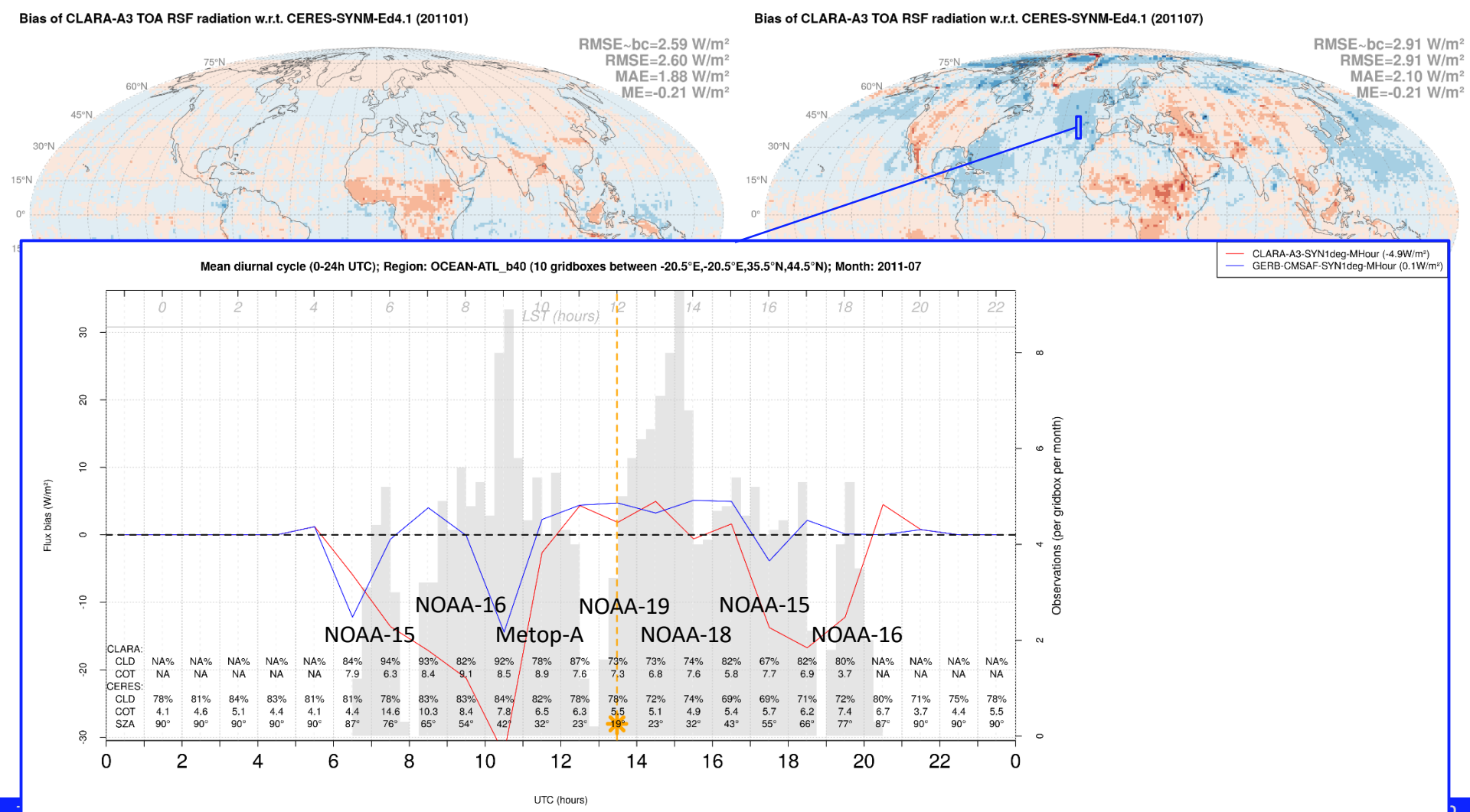
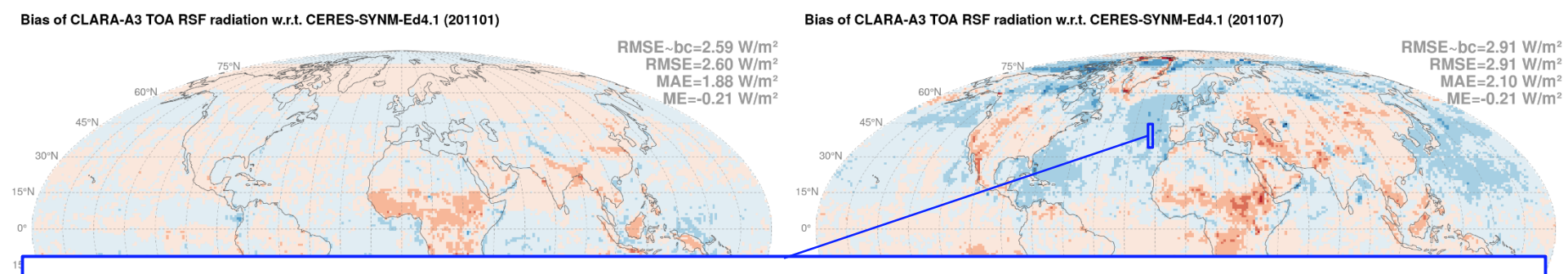
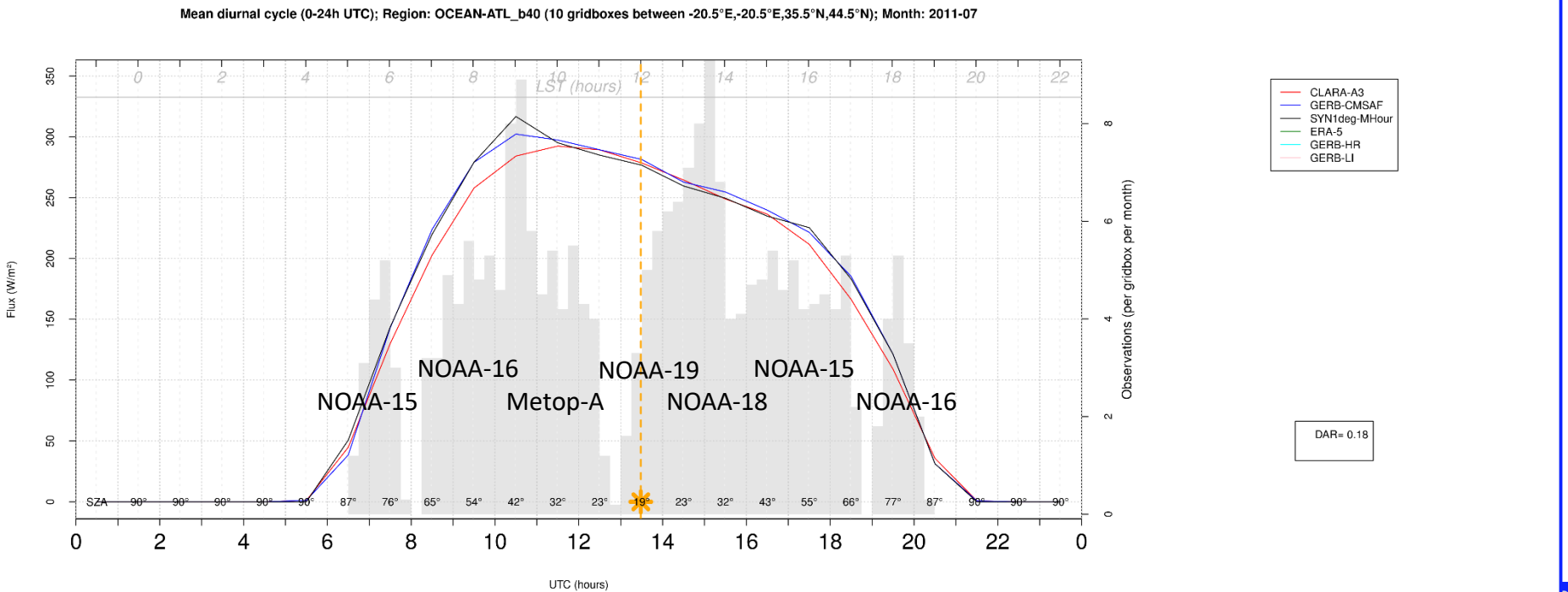
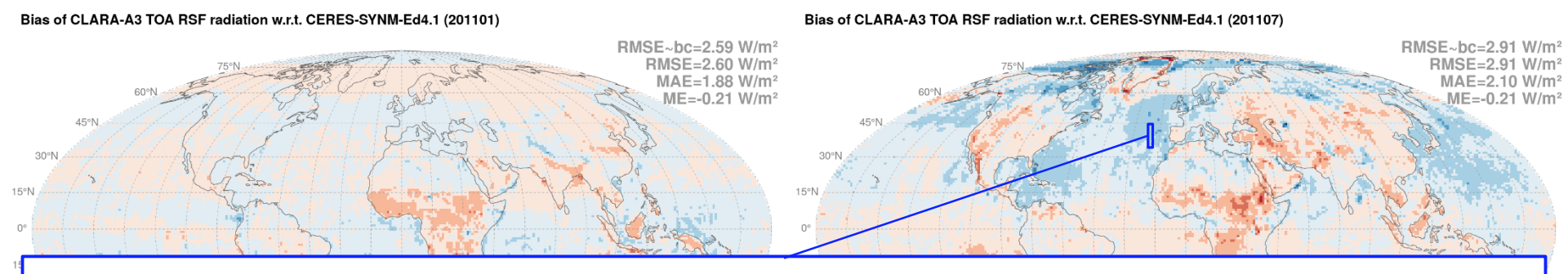
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²

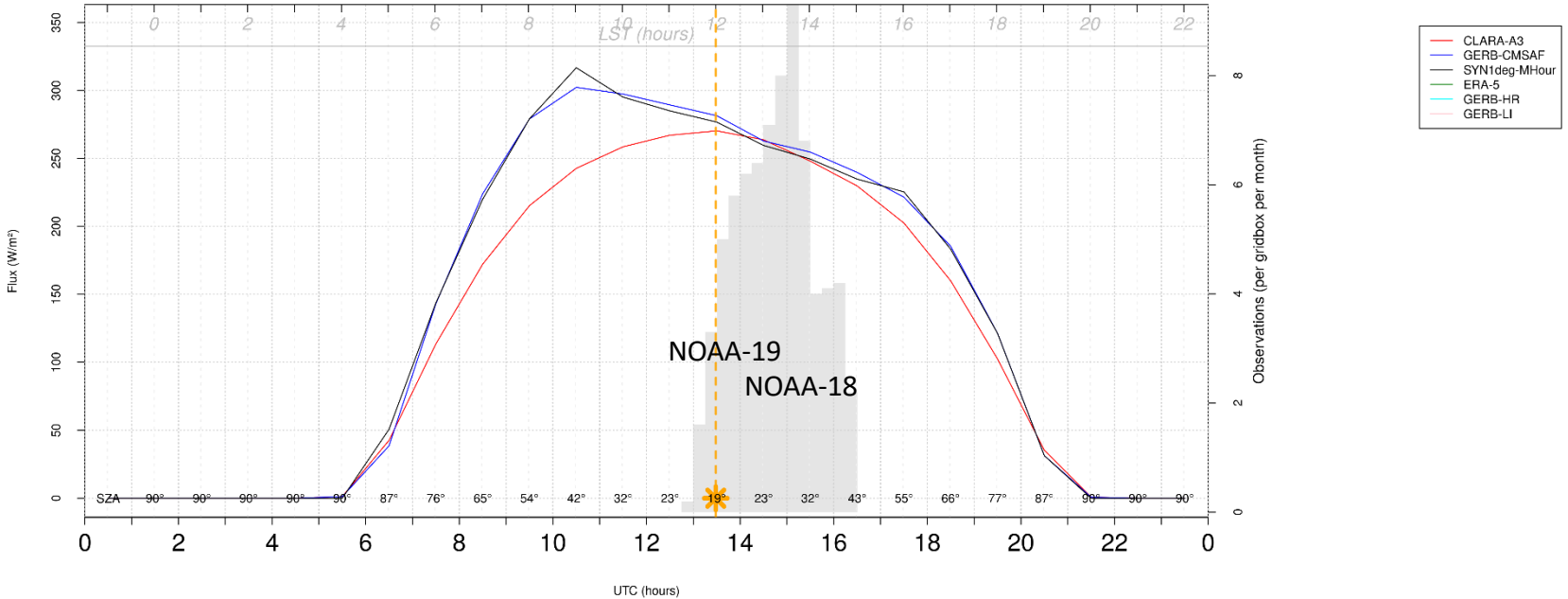

Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_b40 (10 gridboxes between -20.5°E,-20.5°E,35.5°N,44.5°N); Month: 2011-07
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
ERA-5
GERB-HR
GERB-LI
DAR= 0.18
NOAA-15
NOAA-16
Metop-A
NOAA-19
NOAA-18
NOAA-15
NOAA-16
SZA

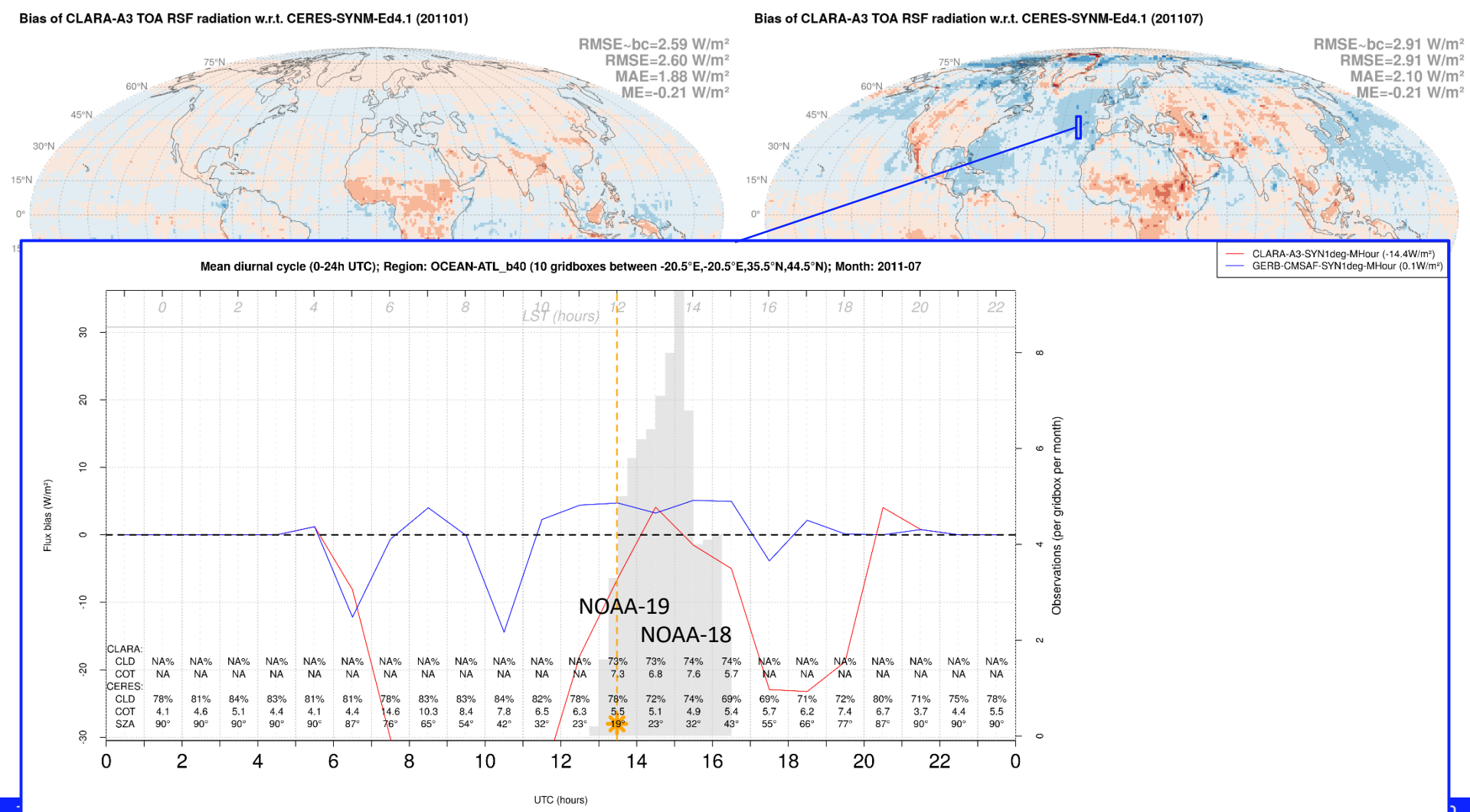

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
RMSE~bc=2.59 W/m²
RMSE=2.60 W/m²
MAE=1.88 W/m²
ME=-0.21 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²
CLARA-A3-SYN1deg-MHour (-4.9W/m²)
GERB-CMSAF-SYN1deg-MHour (0.1W/m²)
Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_b40 (10 gridboxes between -20.5°E,-20.5°E,35.5°N,44.5°N); Month: 2011-07
LST (hours)
Flux bias (W/m²)
Observations (per gridbox per month)
UTC (hours)
NOAA-15
NOAA-16
Metop-A
NOAA-19
NOAA-18
NOAA-15
NOAA-16
CLARA:
CLD NA% NA% NA% NA% NA% 84% 94% 93% 82% 92% 78% 87% 73% 73% 74% 82% 67% 82% 80% NA% NA% NA% NA%
COT NA NA NA NA NA 7.9 6.3 8.4 9.1 8.5 8.9 7.6 7.3 6.8 7.6 5.8 7.7 6.9 3.7 NA NA NA NA
CERES:
CLD 78% 81% 84% 83% 81% 81% 78% 83% 83% 84% 82% 78% 78% 72% 74% 69% 69% 71% 72% 80% 71% 75% 78%
COT 4.1 4.6 5.1 4.4 4.1 4.4 14.6 10.3 8.4 7.8 6.5 6.3 5.5 5.1 4.9 5.4 5.7 6.2 7.4 6.7 3.7 4.4 5.5
SZA 90° 90° 90° 90° 90° 87° 76° 65° 54° 42° 32° 23° 19° 23° 32° 43° 55° 66° 77° 87° 90° 90° 90°

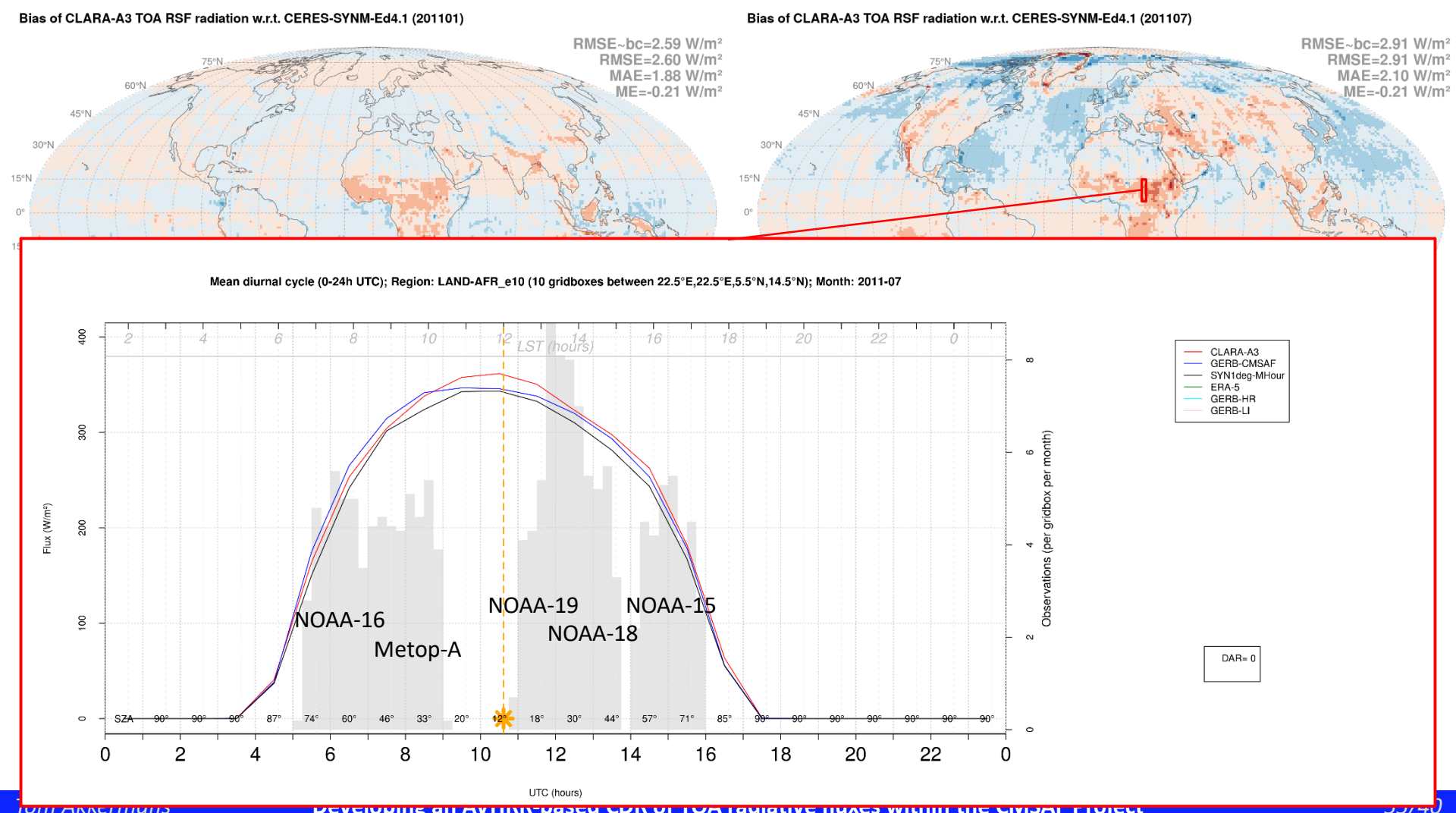

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
RMSE~bc=2.59 W/m²
RMSE=2.60 W/m²
MAE=1.88 W/m²
ME=-0.21 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²

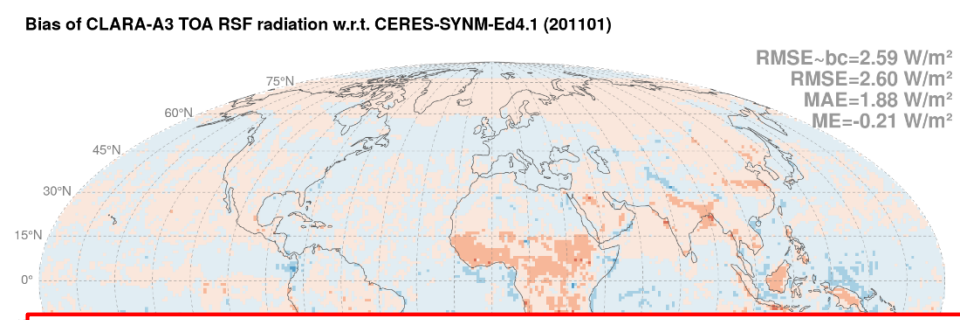

Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_b40 (10 gridboxes between -20.5°E,-20.5°E,35.5°N,44.5°N); Month: 2011-07
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
ERA-5
GERB-HR
GERB-LI
DAR= 0.18
NOAA-15
NOAA-16
Metop-A
NOAA-19
NOAA-18
NOAA-15
NOAA-16
SZA

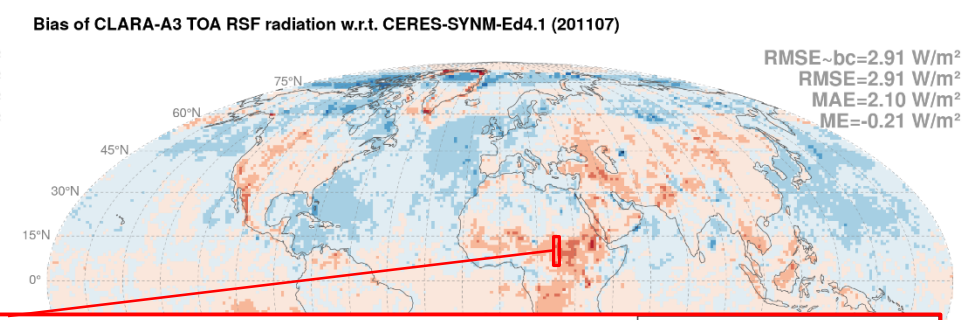

Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
RMSE~bc=2.59 W/m²
RMSE=2.60 W/m²
MAE=1.88 W/m²
ME=-0.21 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²
75°N
60°N
45°N
30°N
15°N
0°

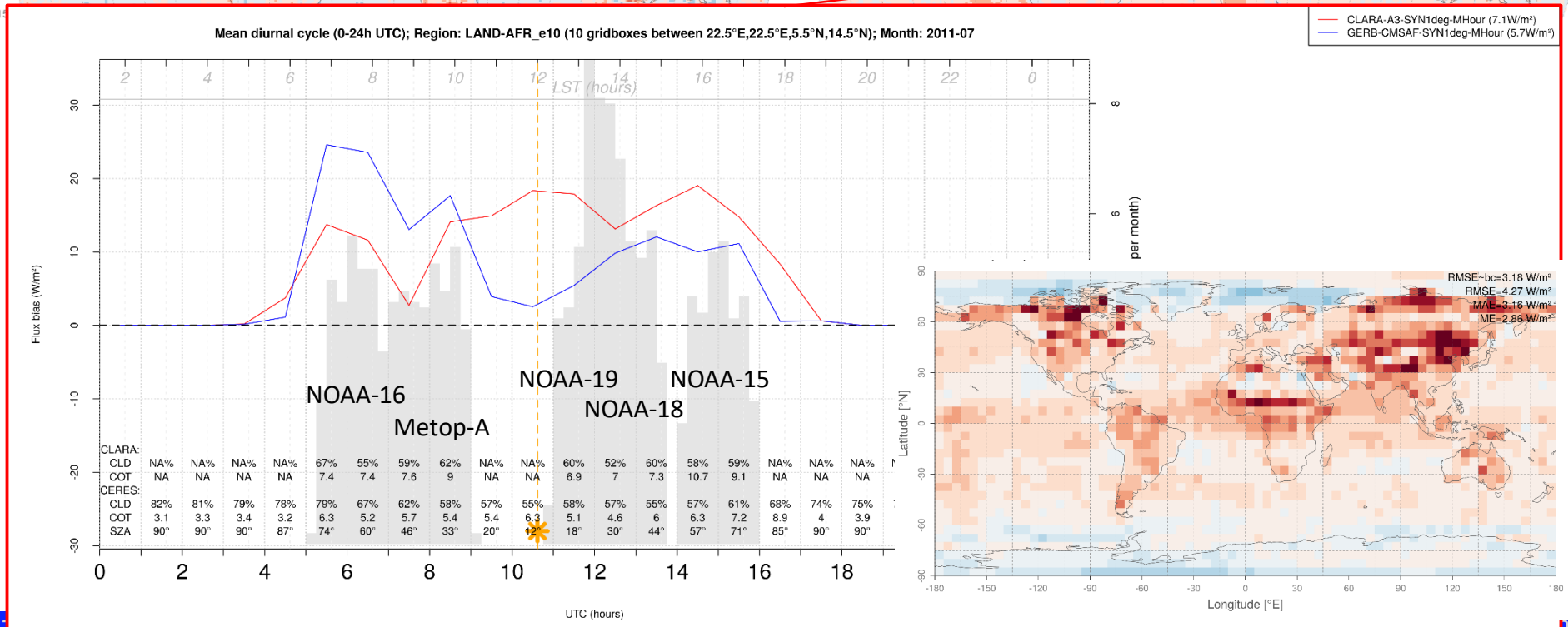

Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_b40 (10 gridboxes between -20.5°E,-20.5°E,35.5°N,44.5°N); Month: 2011-07
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
ERA-5
GERB-HR
GERB-LI
NOAA-19
NOAA-18
SZA
90° 90° 90° 90° 90° 87° 76° 65° 54° 42° 32° 23° 19° 23° 32° 43° 55° 66° 77° 87° 90° 90° 90°


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
RMSE~bc=2.59 W/m²
RMSE=2.60 W/m²
MAE=1.88 W/m²
ME=-0.21 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²
CLARA-A3-SYN1deg-MHour (-14.4W/m²)
GERB-CMSAF-SYN1deg-MHour (0.1W/m²)
Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATL_b40 (10 gridboxes between -20.5°E,-20.5°E,35.5°N,44.5°N); Month: 2011-07
LST (hours)
Flux bias (W/m²)
Observations (per gridbox per month)
UTC (hours)
NOAA-19
NOAA-18
CLARA:
CLD NA% NA% NA% NA% NA% NA% NA% NA% NA% NA% NA% NA% 73% 73% 74% 74% NA% NA% NA% NA% NA% NA% NA%
COT NA NA NA NA NA NA NA NA NA NA NA NA 7.3 6.8 7.6 5.7 NA NA NA NA NA NA NA
CERES:
CLD 78% 81% 84% 83% 81% 81% 78% 83% 83% 84% 82% 78% 78% 72% 74% 69% 69% 71% 72% 80% 71% 75% 78%
COT 4.1 4.6 5.1 4.4 4.1 4.4 14.6 10.3 8.4 7.8 6.5 6.3 5.5 5.1 4.9 5.4 5.7 6.2 7.4 6.7 3.7 4.4 5.5
SZA 90° 90° 90° 90° 90° 87° 76° 65° 54° 42° 32° 23° 19° 23° 32° 43° 55° 66° 77° 87° 90° 90° 90°


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
RMSE~bc=2.59 W/m²
RMSE=2.60 W/m²
MAE=1.88 W/m²
ME=-0.21 W/m²
Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²
Mean diurnal cycle (0-24h UTC); Region: LAND-AFR_e10 (10 gridboxes between 22.5°E,22.5°E,5.5°N,14.5°N); Month: 2011-07
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
NOAA-16
Metop-A
NOAA-19
NOAA-18
NOAA-15
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
ERA-5
GERB-HR
GERB-LI
DAR= 0


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201101)
RMSE~bc=2.59 W/m²
RMSE=2.60 W/m²
MAE=1.88 W/m²
ME=-0.21 W/m²
75°N
60°N
45°N
30°N
15°N
0°


Bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (201107)
RMSE~bc=2.91 W/m²
RMSE=2.91 W/m²
MAE=2.10 W/m²
ME=-0.21 W/m²
75°N
60°N
45°N
30°N
15°N
0°

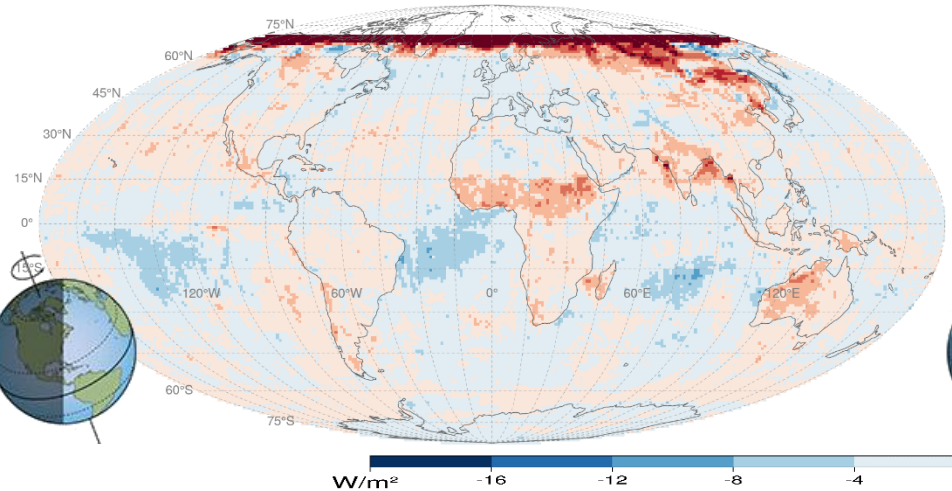

Mean diurnal cycle (0-24h UTC); Region: LAND-AFR_e10 (10 gridboxes between 22.5°E,22.5°E,5.5°N,14.5°N); Month: 2011-07
CLARA-A3-SYN1deg-MHour (7.1W/m²)
GERB-CMSAF-SYN1deg-MHour (5.7W/m²)
LST (hours)
per month)
Flux bias (W/m²)
UTC (hours)
NOAA-16
Metop-A
NOAA-19
NOAA-18
NOAA-15
CLARA:
CLD NA% NA% NA% NA% 67% 55% 59% 62% NA% NA% 60% 52% 60% 58% 59% NA% NA% NA%
COT NA NA NA NA 7.4 7.4 7.6 9 NA NA 6.9 7 7.3 10.7 9.1 NA NA NA
CERES:
CLD 82% 81% 79% 78% 79% 67% 62% 58% 57% 55% 58% 57% 55% 57% 61% 68% 74% 75%
COT 3.1 3.3 3.4 3.2 6.3 5.2 5.7 5.4 5.4 6.3 5.1 4.6 6 6.3 7.2 8.9 4 3.9
SZA 90° 90° 90° 87° 74° 60° 46° 33° 20° 12° 18° 30° 44° 57° 71° 85° 90° 90°
RMSE~bc=3.18 W/m²
RMSE=4.27 W/m²
MAE=3.16 W/m²
ME=2.86 W/m²
Latitude [°N]
Longitude [°E]

2.2. Validation daily/monthly L3

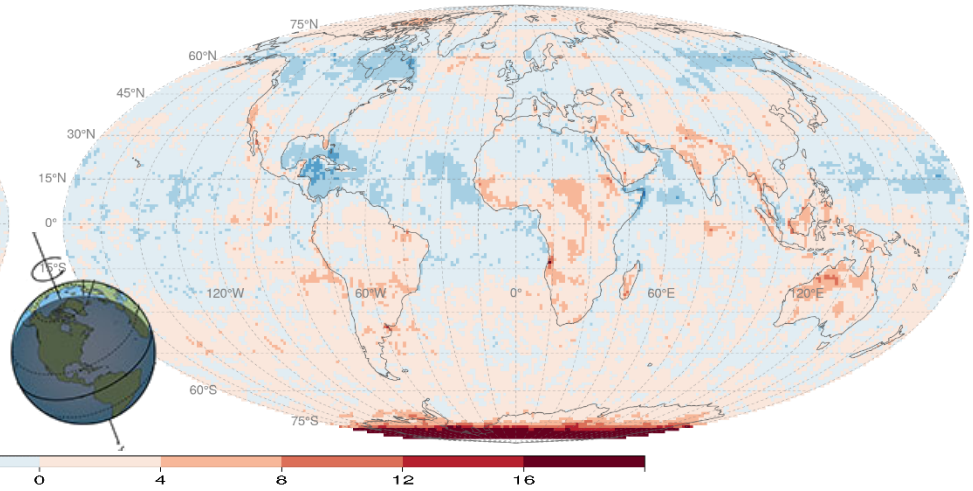
- 2008

- 2008

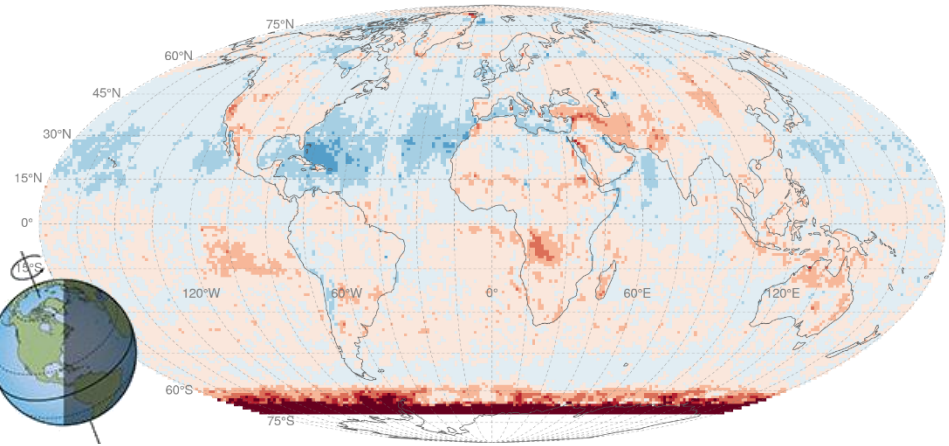
Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200801) ME=104.41 %; MAE=104.41 %



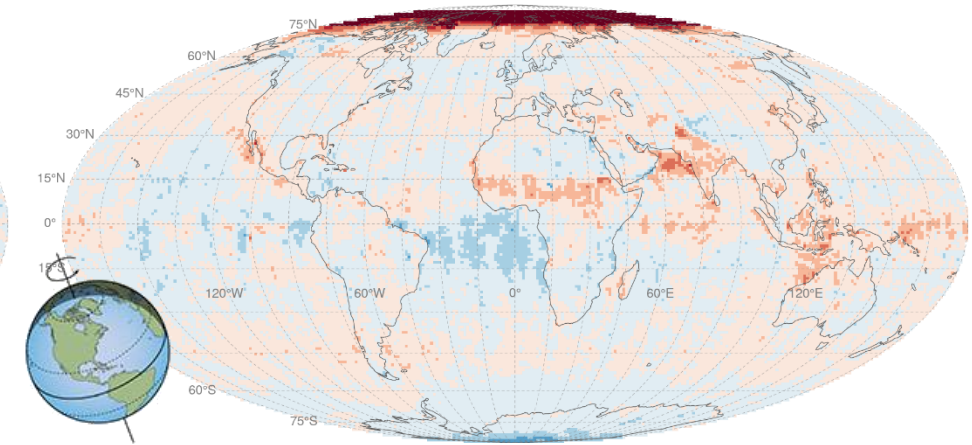
Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200804) ME=95.34 %; MAE=95.34 %

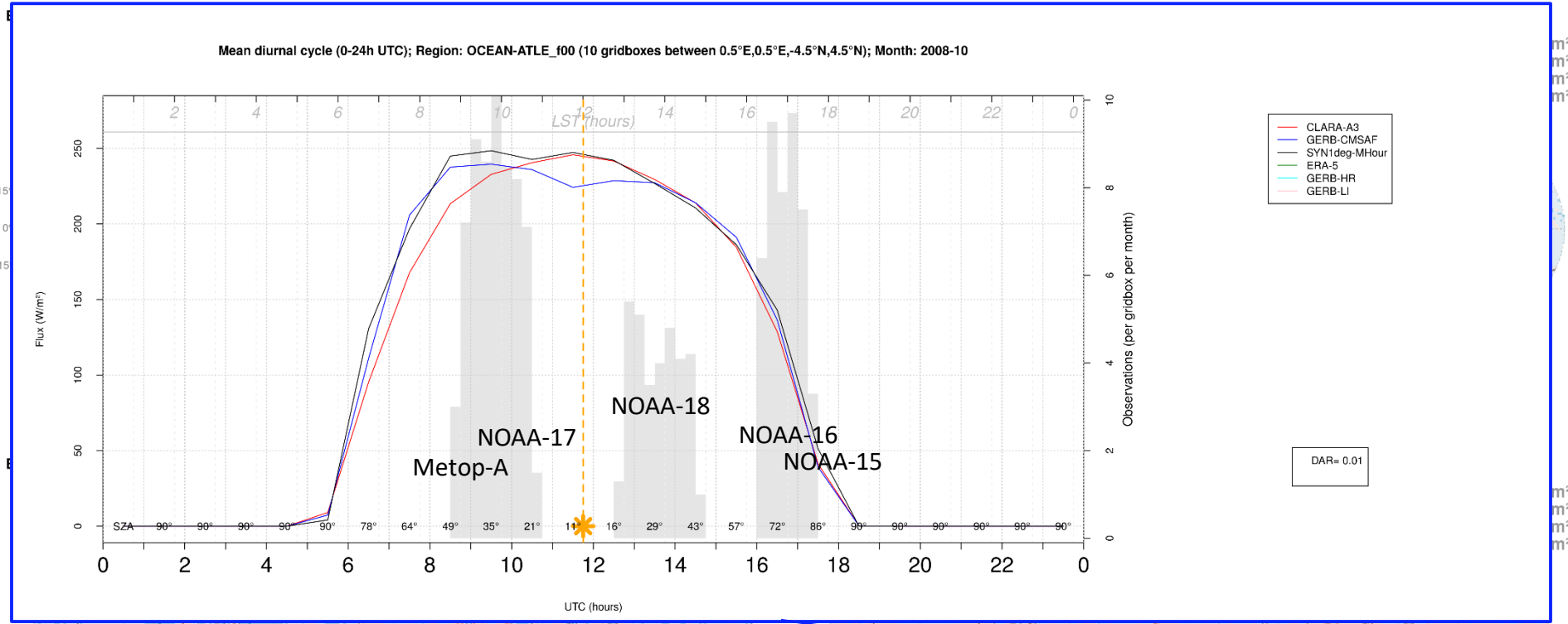


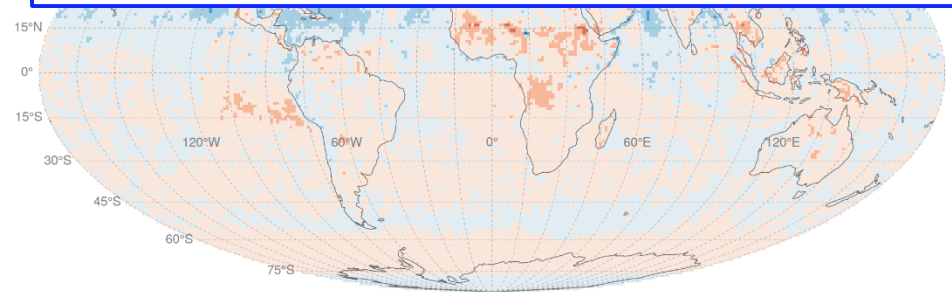
Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200807) ME=91.14 %; MAE=91.14 %

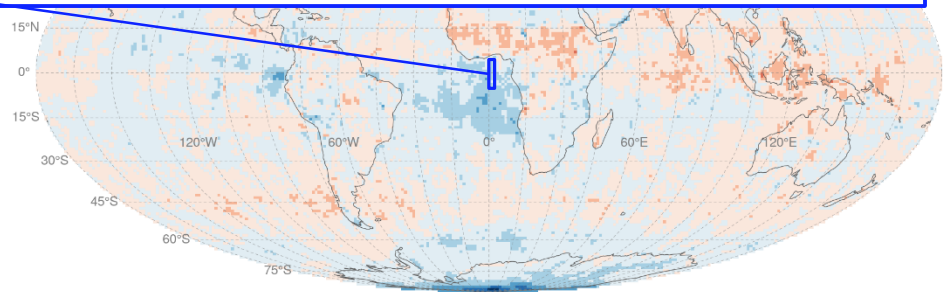


Rel.bias of CLARA-A3 TOA RSF radiation w.r.t. CERES-SYNM-Ed4.1 (200810) ME=97.68 %; MAE=97.68 %

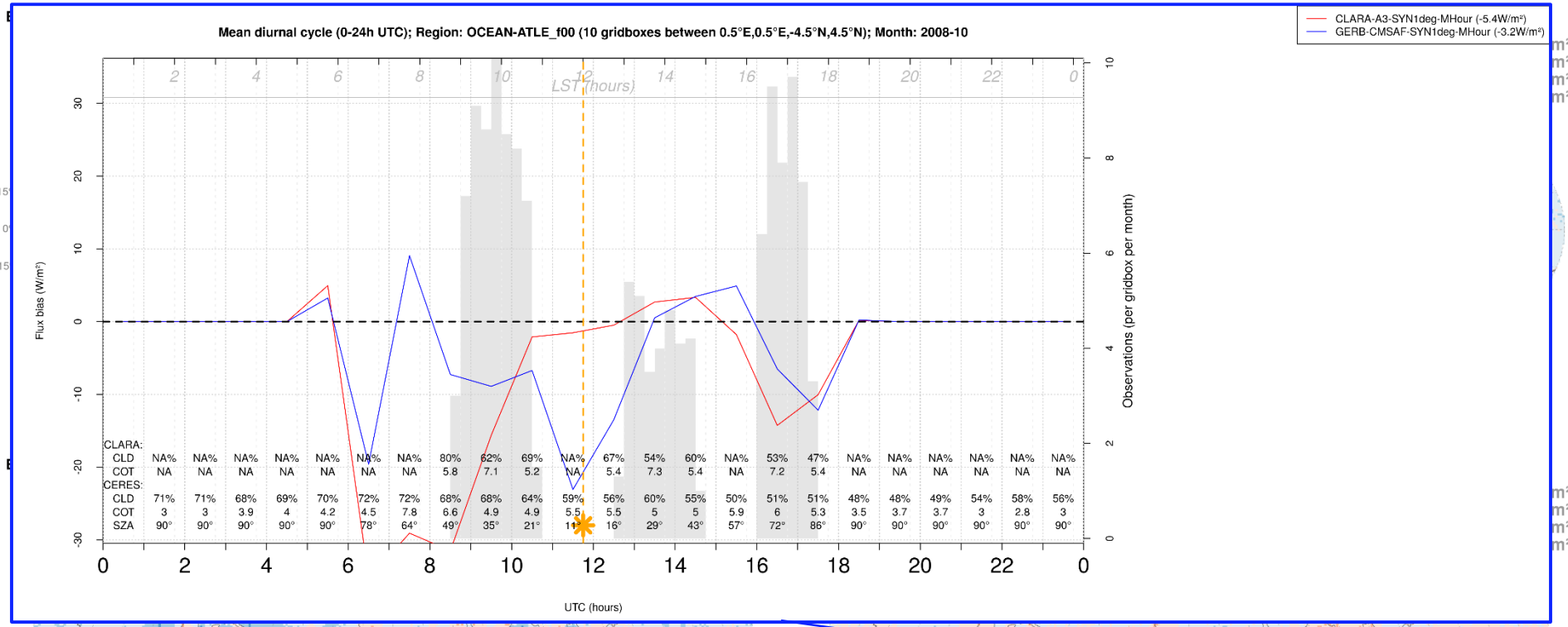


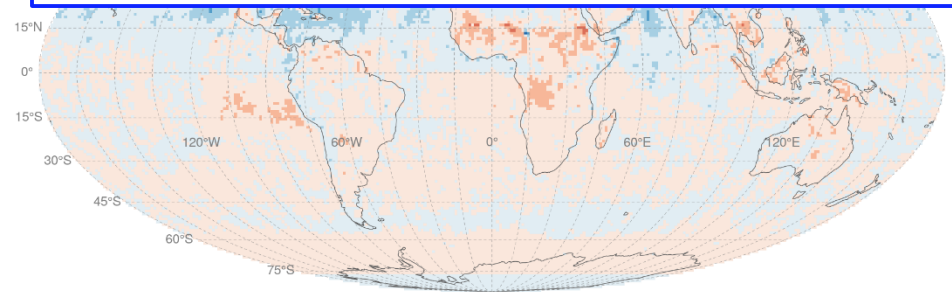

Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATLE_f00 (10 gridboxes between 0.5°E,0.5°E,-4.5°N,4.5°N); Month: 2008-10
LST (hours)
Flux (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA-A3
GERB-CMSAF
SYN1deg-MHour
ERA-5
GERB-HR
GERB-LI
DAR= 0.01
NOAA-18
NOAA-17
Metop-A
NOAA-16
NOAA-15
SZA

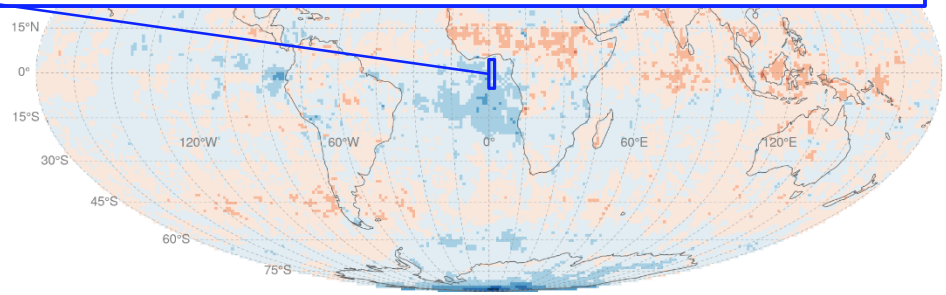

15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E


15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E

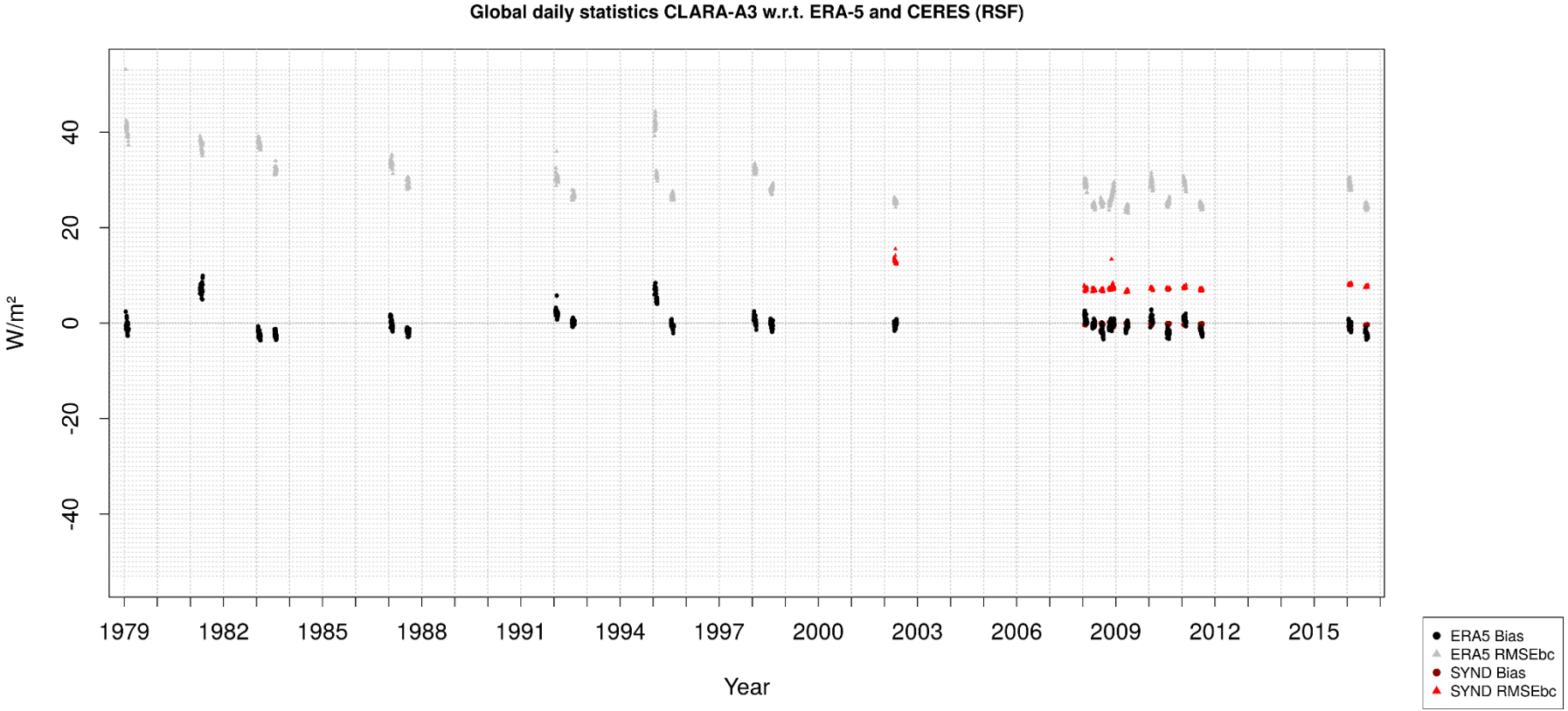

W/m²
-16
-12
-8
-4
0
4
8
12
16

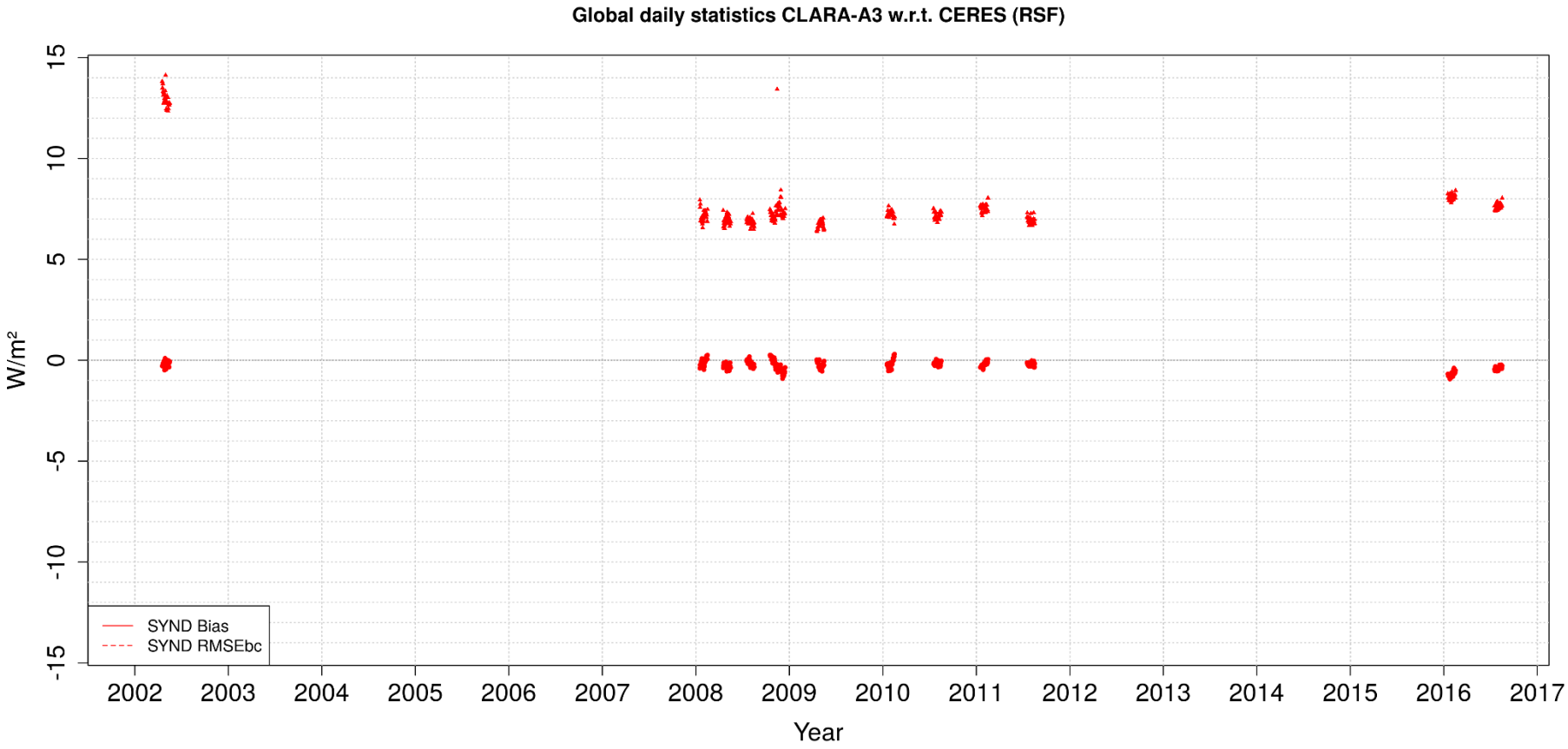

Mean diurnal cycle (0-24h UTC); Region: OCEAN-ATLE_f00 (10 gridboxes between 0.5°E,0.5°E,-4.5°N,4.5°N); Month: 2008-10
CLARA-A3-SYN1deg-MHour (-5.4W/m²)
GERB-CMSAF-SYN1deg-MHour (-3.2W/m²)
LST (hours)
Flux bias (W/m²)
Observations (per gridbox per month)
UTC (hours)
CLARA:
CLD NA% NA% NA% NA% NA% NA% NA% 80% 82% 69% NA% 67% 54% 60% NA% 53% 47% NA% NA% NA% NA% NA% NA%
COT NA NA NA NA NA NA NA 5.8 7.1 5.2 NA 5.4 7.3 5.4 NA 7.2 5.4 NA NA NA NA NA NA
CERES:
CLD 71% 71% 68% 69% 70% 72% 72% 68% 68% 64% 59% 56% 60% 55% 50% 51% 51% 48% 48% 49% 54% 58% 56%
COT 3 3 3.9 4 4.2 4.5 7.8 6.6 4.9 4.9 5.5 5.5 5 5 5.9 6 5.3 3.5 3.7 3.7 3 2.8 3
SZA 90° 90° 90° 90° 90° 78° 64° 49° 35° 21° 11° 16° 29° 43° 57° 72° 86° 90° 90° 90° 90° 90° 90°


15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E


15°N
0°
15°S
30°S
45°S
60°S
75°S
120°W
60°W
0°
60°E
120°E


W/m²
-16
-12
-8
-4
0
4
8
12
16


Global daily statistics CLARA-A3 w.r.t. ERA-5 and CERES (RSF)
W/m²
40
20
0
-20
-40
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015
Year
ERA5 Bias
ERA5 RMSEbc
SYND Bias
SYND RMSEbc


Global daily statistics CLARA-A3 w.r.t. CERES (RSF)
W/m²
15
10
5
0
-5
-10
-15
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
SYND Bias
SYND RMSEbc